Prosperity Within Limits?
Planetary Habitability, Global Convergence and Structural Transformation, 2026-2100*

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Abstract. We analyze under what conditions global income convergence by 2100 is compatible with limiting temperature rise to below 2°C. To this end, we construct a new historical multi-sector global database (57 countries and regions, 1970–2025) and build an input-output projection model to 2100. Unlike standard climate-economy models, we examine sectoral reallocation toward immaterial sectors as a climate determinant, rather than treating it as a byproduct of development. In our benchmark scenario, all countries reach 60k euros (2025 PPP) in per capita GDP in 2100, close to today's richest-country levels. We find that this compatible with 2°C only under very strict conditions: a reduction of work hours, a consumption shift toward immaterial sectors, a major change in food habits, and a fast energy transition requiring massive low-carbon investment. The "Sustainable Convergence" scenario delivers higher comprehensive well-being (including valuations of time and planetary habitability) across all regions than "Productivist Convergence" or "Persistent Inequality" scenarios, both yielding a much larger global GDP but temperature rise beyond 4°C by 2100. Our main conclusion is that global between-country convergence within planetary boundaries requires major structural transformation and a decisive move toward sufficiency: rapid energy transition alone will not suffice.

*All series constructed in this research are available online in the World Sectoral Economy-Environment Database (wseed.world), together with a replication package including all raw data sources, methods and codes. We thank several colleagues for their helpful feedback: Fabian Aponte, Gabriele Dabbaghian, Rutger Hoekstra, Lena Kilian, Julien Lefèvre, Céline Guivarch, Narasimha Rao, Inge Schrijver, and Kirsten Wiebe, as well as seminar participants at the World Inequality Lab and at Sciences Po. The report benefited from the support of the European Union under a Horizon 2020 grant (WISE Horizons #101095219).
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1. Introduction

What level of economic prosperity and well-being is compatible with global convergence (equality between countries) and the preservation of planetary habitability, in particular with limiting global anthropogenic temperature rise to below 2°C? Or, to put it differently, what kind of structural transformation is needed and how should we redefine the notions of prosperity and well-being so that the objective of global convergence between countries does not compromise planetary habitability?

The challenge of reconciling global economic development with planetary habitability and climate stability represents one of the defining questions of the 21st century. As the latest Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) makes clear, limiting global warming to 2°C above pre-industrial levels requires rapid, far-reaching, and unprecedented changes in all aspects of society (IPCC, 2022). At the same time, the world remains extremely unequal (Chancel et al. 2026). Importantly, this applies not only to income and wealth but also more basic services like education and health which are distributed highly unequally across the world, limiting the speed of convergence (Bharti et al., 2026).

In this paper, we build a new historic multi-sector global database including series on GDP, consumption, labour hours, and carbon emissions as well as an input-output projection model to bring new answers to these fundamental questions. Our main objective is to analyze multisector development scenarios whereby all world countries converge to the same per capita GDP by 2100. We explore under what conditions these are compatible with limiting global anthropogenic temperature rise to below 2°C above pre-industrial levels. In our benchmark scenario, all countries converge to 60k euros in per capita GDP in 2100 (using fixed 2025 PPP prices), close to today's levels in the world's richest countries. We find that rapid energy decarbonization is necessary but not sufficient: compatibility with the 2°C target also requires sufficiency, defined as a major structural transformation aimed at reducing the economy's material footprint. This includes a drastic reduction in work hours, a large consumption shift from material to immaterial sectors, and a substantial change of food habits. In other words, decarbonization without sufficiency will not suffice. In turn, sufficiency also requires deep institutional and distributional changes.

The justification for focusing on global convergence scenarios is straightforward. First, several non-Western countries have already been well engaged in – or in some cases have already completed – a trajectory of convergence in per capita GDP with the richest Western countries. Next, all Global South countries aspire to economic prosperity, and any analytically credible and politically viable framework for global climate cooperation must account for this aspiration. Of course, the question of the time horizon for complete convergence remains open and uncertain. In our benchmark scenario, we set the convergence date to 2100, which seems sufficiently far to be plausible. Our multisector model can easily be amended to study scenarios using an alternative date. It can also be used to study convergence involving different GDP targets. This allows us to analyze the extent to which lower GDP levels are necessary in order to ensure the preservation of planetary habitability (see Figures 1a-1c).

In our core “Sustainable Convergence” (SC) scenario, all countries reach the target of 60k euros (2025 PPP prices), through differential GDP per capita growth rates of around 0-0.5% in today’s richest regions (North America/Oceania, Europe) and around 3-4% in today’s poorest regions (Subsaharan Africa, South & Southeast Asia), the latter comparable to the average growth rate of East Asia across the last 75 years. At the same time, enabled by increased productivity, global working hours halve to around 1000 annual work hours per employed individual. This is in line with the long-run decline in labour hours observed over the 1800-2025 period. This allows for a substantial limitation of aggregate GDP growth and material footprint, in comparison to scenarios without such worktime reduction.

We also project an acceleration of the shift to services in the world economy by reducing the share of material sectors in aggregate consumption and investment expenditure by 30%, and by giving the priority to education and health within the immaterial sectors. As a result, the share of global labour hours in education, health and public services rises from 11% in 2025 to 43% in 2100. While this may appear relatively large, we stress that this share is already about 30-35% in countries like Norway or Sweden in 2025.

The third element of sufficiency is a substantial transformation of food patterns. North American red meat consumption would need to fall by a factor of around 4.5 by 2100, and Western European by around 2.5, consistent with a 25% global reduction in grazing land (including a 40% reduction in Latin America), a complete ban on deforestation, and a major reforestation plan. These land-use changes are required both to limit agricultural emissions and to restore carbon absorption capacity through reforestation, replacing the large-scale carbon capture and removal technologies that many climate scenarios assume but that remain technologically unproven.

We also model two alternative scenarios, “Persistent Inequality” (PI) and “Productivist Convergence” (PC), which project continued between-country inequality and global convergence at much higher GDP per capita levels than SC, respectively. Unlike SC, both PI and PC abstain from the key sufficiency elements of a reduction in labour hours, shifts in consumption patterns, and changes of food habits.

These macroeconomic scenarios are combined with different scenarios on decarbonization of the energy system, which are broadly aligned with the policy scenarios outlined by the World Energy Outlook 2025 of the International Energy Agency (IEA). In particular, we distinguish between a “Slow Decarbonization” scenario (which roughly corresponds to current policies), an “Intermediate Decarbonization” scenario (in line with official country commitments) and a “Fast Decarbonization” scenario (involving substantially faster rise of renewable energy sources and phase-out of fossil fuels). Importantly, one significant difference with most IEA and IPCC scenarios is that we do not assume large-scale carbon capture and removal to achieve net zero – relying instead on the land-use changes described above.[1]

The different decarbonization scenarios are related to different levels of investment in low-carbon energy systems. This entails both an increase in investments in new low-carbon assets as well as a re-structuring of existing investments away from high-carbon assets. Under the Sustainable Convergence scenario, we assume that there is a large increase in investments in low-carbon energy, equivalent to about 3-4% of world GDP annually over the next three decades, which would deliver a rapid decarbonization of the production systems.[2] We also make projections regarding the other capital investment and human capital expenditure (education, health) that are needed in order to ensure global convergence and fast productivity growth in the world’s poorest regions (especially Subsaharan Africa and South & Southeast Asia). We additionally evaluate the compensation for the countries that are the most strongly affected by the land-use changes and reforestation plans (particularly Latin America).

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[1] Due to high costs, numerous large-scale demonstration projects of carbon capture have been delayed or abandoned, and the volumes required are enormous relative to anything demonstrated so far. Long-term underground storage carries potential risks of leakage, and suitable sequestration sites are not universally available. Direct air capture faces even greater uncertainty as it remains extremely costly and has barely moved beyond pilot scale. Based on these uncertainties we consider large-scale deployment of both technologies as highly speculative (Jones and Lawson, 2022; Oreskes, 2024), and assume only limited carbon capture at industrial sites in our most optimistic projections.

[2] The estimates for additional investments required for rapid decarbonization are based on our own synthesis and updating of previous estimates, including those published by Working Group III of the IPCC AR6 (IPCC 2022) and Climate Policy Institute (Buchner et al., 2023; Climate Policy Institute, 2025), who compute total annual climate investment requirements to achieve a net zero scenario based on a review of estimates of the costs to de-carbonize various sectors of the economy.

Overall, we estimate the total financing needs associated with the Sustainable Convergence scenario at about 10-12% of world GDP annually over 2030-2060.

Using an input-output framework to model these transitions across the 21st century, we find that the Sustainable Convergence scenario combined with Fast Decarbonization stays just within the 2°C target. Our main conclusion is that sustainable development for all countries requires a decisive move toward sufficiency: changing energy systems alone will not suffice. Our benchmark alternative scenarios PC and PI, which lack both fast decarbonization and sufficiency, result in temperature rise beyond 4°C. Overall, our SC scenario substantially improves comprehensive well-being indicators (including valuation of leisure time and planetary habitability, across a wide range of welfare functions) in comparison to the two other scenarios.

To summarize, we find that the preservation of planetary habitability is compatible with substantial growth in poor countries and global convergence between poor and rich countries, but only if rich countries stop growing almost entirely (via a drastic reduction of labour hours) and go through a large reallocation from material to immaterial sectors and change in food habits. We also simulate global convergence scenarios with substantial absolute degrowth for rich countries (e.g. 15k, 30k or 45k euros in per capita GDP for all countries in 2100 rather than 60k euros). We find that this could lead to significantly better outcomes on the climate front, with a limitation of temperature rise close to 1.5°C by 2100. We also find that the sectoral composition matters – and not only the level. For instance, we project that a 60k euros target with large shifts from material to immaterial sectors and in food habits can lead to lower long-run temperatures than a 30k euros target or even a 15k euros target with no such shift (which is also harder to do with 15k euros rather than 60k euros). In other words, targeted sufficiency can be more effective than large uniform degrowth. We hope that these simulations spanning energy transition, sectoral change, sufficiency, and degrowth trajectories can contribute to open new ground for both academic and public discussion on these fundamental issues.

We also discuss the set of policy tools and institutional changes (including income and wealth redistribution, public sector extension, non-linear carbon pricing and quantity controls) that could support the implementation of the Sustainable Convergence scenario. However, we should emphasize that we do not attempt in the present paper to provide a full-fledged distributional and institutional analysis of the SC scenario. We focus on the analysis of the multisector production and expenditure trajectories associated with the different scenarios, and on their impact on emissions and global warming. Given that the SC scenario comes with substantial financing needs (about 10-12% of global GDP annually over the next three decades), it is clear that such a plan requires major distributional and institutional changes in order to attract majority support. The most natural solution is that the financing needs should be met by the global rich, via a major compression of income and wealth inequality, so that lower and middle-income groups do not lose. We leave the comprehensive analysis of the corresponding trajectories, including within-country and between-country income and wealth inequality, institutional changes, and political acceptability, to our companion paper devoted to distributional pathways (Bothe et al., 2026).

This work is closely related to several literatures at the intersection of climate-economy modelling, structural transformation, comparative development, and inequality studies. First, and perhaps most closely related, is the large literature on scenario-based climate modelling which explores future economic pathways and climate mitigation scenarios to test if they are likely compatible with a given carbon budget (Guivarch et al. 2022). The literature on the “Shared Socioeconomic Pathways” (O’Neill et al. 2014; Riahi et al. 2017), which has formed the scientific basis for the IPCC Assessment Reports, is largely based on Integrated Assessment Models (IAM) that, while often disaggregating the energy sector in detail, provide limited disaggregation of non-energy sectors and therefore rarely study the role of structural transformation toward immaterial sectors. This literature tends to take a supply-side, technology-based perspective on climate mitigation. In this study, we complement existing approaches by deploying an input-output framework to model demand-side structural transformation – in particular the reallocation of consumption and labour toward immaterial sectors – as an explicit climate mitigation lever. Further, the existing IAM literature and the IPCC have been criticized for perpetuating global inequality under their scenarios (Kanitkar et al. 2024). We address this by evaluating scenarios with full income convergence between countries by 2100, contrasting our assumptions with those of the IPCC-SSP scenarios.

Second, through the focus on the sectoral structure of the economy, our work is related to the literature on the links between structural transformation and its environmental implications: services are generally less emission-intensive than manufacturing, suggesting that the "natural" trajectory of development may be environmentally beneficial (Stern, 2004; Henriques & Kander, 2010; Aghion et al., 2025). However, this optimism is tempered by evidence that service-led growth in wealthy nations has been accompanied by offshoring of material production, with embodied emissions appearing in trade flows rather than disappearing (Wiedmann et al., 2015; Dorninger et al., 2021, Hickel and Kallis, 2020). Lefèvre et al. (2022) integrate structural change into climate scenario analysis using input-output methods, finding that sectoral composition substantially affects mitigation pathways. Our paper advances this literature by modelling sectoral changes not as a byproduct of development but as a deliberate climate strategy, asking what role accelerated policy-induced reallocation toward immaterial sectors (education, health, culture) can play in reconciling global income convergence with the 2°C target.

Third, our work is closely related to recent attempts at using environmentally-extended input-output frameworks to study scenarios that incorporate structural change. Environmentally-extended input-output (EE-IO) analysis, building on Leontief's (1970) seminal input-output framework, has become the dominant methodology for consumption-based emissions accounting and footprint analysis. The development of global multi-regional input-output (MRIO) databases, including EXIOBASE (Stadler et al., 2018), EORA (Lenzen et al., 2013), and WIOD (Timmer et al., 2015), enables researchers to trace emissions embodied in international supply chains, revealing the substantial displacement of environmental burdens from consuming to producing nations (Peters & Hertwich, 2008; Wiedmann & Lenzen, 2018). However, applying IO methods to long-run scenario analysis poses methodological challenges: standard IO tables are static snapshots, whereas projections require evolving technical coefficients and shifting demand structures. Recent work addresses this gap. De Koning et al. (2016) construct trade-linked IO scenarios consistent with 2°C pathways. Lefèvre (2024) provides a systematic bridge between IO analysis and integrated assessment models, demonstrating complementarities in sectoral detail and technology representation. Our paper contributes to this emerging literature by constructing IO-based scenarios to 2100 that explicitly model sectoral consumption shifts and the energy transition as changes in both final demand composition and technical coefficients.

Fourth, our work speaks to the debate between “green growth”, “degrowth”, and sufficiency. Degrowth challenges the foundational assumption that continued economic growth is compatible with ecological sustainability, arguing instead for a planned reduction of material and energy throughput in wealthy nations to achieve environmental goals while maintaining wellbeing (Kallis, 2011; Hickel, 2021). Proponents contend that efficiency gains alone cannot deliver the emission reductions required for sustainable emission pathways, a claim supported by evidence of persistent coupling between GDP and material footprints (Wiedmann et al., 2020; Haberl et al., 2020) and the failure of absolute decoupling to occur at the pace required

(Parrique et al., 2019). This scholarship also explores macroeconomic frameworks compatible with stable or declining output (Jackson, 2017; Keyßer & Lenzen, 2021). The related sufficiency literature emphasizes reducing demand for resource-intensive goods and services rather than merely greening their production (Toulouse et al., 2019; Sandberg, 2021; Vogel et al. 2021). Closely related is the literature on “decent living standards”, which establishes minimum material prerequisites for human flourishing (Rao & Min, 2018; O'Neill et al., 2018; Steinberger et al., 2012; Millward-Hopkins et al., 2020). Our paper advances and connects these literatures by providing a quantitative framework that, for the first time, simultaneously embeds key mechanisms of each tradition – the material consumption limits of degrowth and sufficiency, the material conditions required for global convergence in living standards, and the technology-driven decoupling of green growth – while treating sectoral reallocation toward immaterial sectors as an explicit climate lever, applied to all world regions under full income convergence by 2100, expressed in concrete sectoral volumes comparable across countries.

The remainder of the paper is organized as follows. In section 2, we present our conceptual framework, sources and methods. In section 3, we describe the macroeconomic assumptions underlying our benchmark global convergence scenario (“Sustainable Convergence”, SC) and the corresponding 2100 targets and post-2100 steady-state development path. In section 4, we present our main alternative comparison scenarios, namely the Persistent Inequality (PI) and the Productivist Convergence (PC) scenarios. In section 5, we outline our assumptions on the evolution of the energy system. In section 6, we examine the consequences of these scenarios on carbon budgets, global warming, and land use. In section 7, we analyse the impact on comprehensive well-being indicators. In section 8, we discuss the ambitious set of policy tools and institutional reforms that are likely needed to implement the SC scenario. Finally, in section 9, we present concluding comments and discuss future research prospects.

2. Conceptual Framework, Sources and Methods

This research relies on the construction of a new database, the World Sectoral Economy-Environment Database (WSEED). All data series and technical details about the construction of our database are described in the replication package available online on our dedicated website (wseed.world). Here we focus on the most substantial issues regarding our accounting framework, data sources and projection methodology. We refer all interested readers to the supplementary online material for additional information.

2.1. Accounting Framework: A Multi-Sector Economy-Environment Database

The general objective of the WSEED database is to describe past and future evolutions of the global economy, including the volumes and values of goods and services produced, consumed, and invested using the following 8-sector classification including five "material sectors" and three "immaterial sectors":

5 Material sectors:
Food (incl. raw agricultural products & processed food)
Housing/Construction (incl. housing services, housing and other construction)
Manufacturing (incl. textiles, electronics, cars, etc.)
Energy (incl. low-carbon energy, fossil energy, mining & water)
Transport (incl. train, bus, air, boat, etc.)

3 Immaterial Sectors:
Education/Health (incl. education, health & other public services)
Leisure/Culture (incl. shops, restaurants, bars, hotels, movies, books, etc.)
Other Services (incl. legal, financial, consulting, computing, architecture, etc.)

These eight economic sectors are partly based on classifications available in existing national accounts (see Table 1), with some changes and adjustments which we further describe below. Generally speaking, a key objective of the database is to be able to make meaningful multidimensional comparisons of production and consumption structures, which can also be related to emission footprints, living standards, and basic needs. The extent to which immaterial sectors are truly immaterial – and/or can become so in the future – is a central issue which we will closely investigate. As a first justification, we highlight the fact that the three immaterial sectors use less inputs per unit of output produced and in particular use less energy than the five material sectors. Note that transport is traditionally classified in the services, but that in practice it has a very substantial material footprint (particularly in terms of energy input), which is why we classify it as a material sector. Some of the 8 sectors will be often broken down into several subsectors for further analysis or modelling.

In particular, Housing/Construction includes both housing services (the rental value of all existing dwellings) and construction (building of new housing and other structures).

Unlike standard national accounts, which group housing services with real estate activities, we treat them separately because housing constitutes a central component of basic needs and household well-being – access to adequate housing being a major determinant of living standards – while also representing a very large economic aggregate.[3] Housing services alone show a very high hourly labour productivity, which largely reflects the imputed rental return on the accumulated stock of housing capital, built through past construction labour. Productivity of the construction sector alone, however, is substantially below average (in effect ignoring the housing services made possible by cumulated past construction work). This distinction is important because the combined sectoral productivity of housing services and construction is above the world economy average.[4] In practice, the aggregate category of Housing/Construction will commonly be broken up into housing services and construction.

Importantly, for our modelling of future emission scenarios we use a much more detailed representation of the energy sector, which is disaggregated in up to fourteen subsectors. Thereby, we not only differentiate between primary fuels, electricity and other activities such as mining and waste management, which are included in the aggregate energy sector, but further disaggregate the electricity sector in up to eight electricity generation technologies (see Table 2).

Our analysis relies on harmonized historical series covering the 1970-2025 period and on scenario-based input-output projections covering the 2026-2100 period. The database includes homogenous global series on sectoral GDP, consumption, investment, labour hours, input coefficients, and greenhouse gas (GHG) emissions using our 8-sector classification, and following the latest national accounts guidelines (SNA 2008). In our benchmark series, the world is broken down into a fixed set of 57 core territories used in the World Inequality Database (WID), including 48 main countries and 9 residual regions (see Table 3). While all analyses rely on these 57 core territories, we often present results using eight aggregate world regions (Europe, North America/Oceania, Latin America, Middle East/North Africa, Subsaharan Africa, Russia/Central Asia, East Asia, South & South-East Asia), and we refer to the Online Appendix for detailed country-level series.[5]

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[3] Around 8% of global GDP in 2025, compared to about 6% for construction, see Table 6 below.

[4] See Appendix A for a more detailed discussion.

[5] We also estimated a set of simulated series covering the 216 WID core countries over the 1970-2100 period. These simulated series are based upon the simplifying assumption that countries with missing information have the same input-output matrices and the same sectoral structure of labour hours and GHG emissions than their residual region.

Our benchmark series are expressed in PPP Euros (based on observed purchasing-power-parity exchange rates with local currency units in 2025) using either current nominal prices p_{ict} or constant 2025 world prices.[6] We focus for the most part on series using constant 2025 world prices, for which we harmonized detailed country-sector relative price series. We normalize all relative prices to 1 in 2025, so that in effect we can ignore changes in relative prices and price differences between countries and concentrate on volume accounting when we analyze series. We also provide series using current nominal prices and market exchange rates (MER), and we discuss the role played by changing relative prices as well as by changing gaps between PPP and MER series. Additionally, we provide series with sector-specific PPP adjustments to compare sectoral consumption levels across countries in more detail.

2.2. Data and Harmonization

The historical database underlying this study was constructed by assembling and harmonizing a large number of data sources. For all macroeconomic variables we provide harmonized series for eight sectors and 57 countries and residual regions from 1970 to 2025. These are supplemented by sectoral emission data starting in 2000. Land use data is provided for eight world regions. In this section, we briefly describe sources, harmonization methods, and some core issues regarding the data construction.[7]

Table 4 provides an overview of the main sources used. These include primarily inter-country input-output and national accounts data sets as well as additional sources for labour hours, GHG emissions, and land use. While cross-country datasets exist for the variables, the breadth of the database – spanning various variables, eight sectors, 57 countries, and 55 years – required substantial data collection and harmonization. In individual cases, additional country-specific sources supplement the main sources listed in Table 4.

All sources are harmonized to the same eight-sector classification described in Section 2.1, by constructing explicit correspondence tables between each source's industry classification and our sector definitions. Often more than one data source is available

[6] All our PPP estimates are based upon the ICP 2021 (the most recent International Comparison Program coordinated by international institutions). We follow standard national accounts guidelines and series. In particular, when some goods or services are provided for free, or at insignificant prices (typically less than half of the costs), for instance education or health or national defense provided by government units, then the monetary values and corresponding price indexes are computed on the basis of production costs.

[7] For further details and sources by variable, see Appendix B and the online replication package.

for a given country and variable. Therefore, we compare the different sources and define for each variable a priority order based on data quality and coverage. To combine the sources into consistent series running from 1970 to 2025, we apply growth-rate-based harmonization: the level of the series for each country is anchored to the highest-priority available source, while lower-priority sources contribute year-on-year growth rates used to extend the series forward and backward in time. This prevents discontinuities from methodological differences across sources. All sources are individually inspected for each country and variable, and outliers are excluded before applying the harmonization.[8]

For all variables, core accounting identities are enforced throughout. First, sectoral values always sum to the total economy aggregates, and the sum across the 57 countries and regions equals the global totals. This also applies to sectoral price deflators and PPP factors, which result in the total economy values when combined with the GDP and GNE series. Moreover, we always provide regional aggregate values, which are the sum of the country series following regional country assignment from Table 3. Second, disaggregated variables always sum to aggregates both for macroeconomic and emissions series. For example, Gross National Expenditure is always the sum of final consumption and investment. Different GHG emissions add up to total GHG emissions expressed in CO2-equivalents. Finally, global accounting identities are assured, among others: GNE and GDP are equal in all years for the global total economy and net trade is zero on the world level for each sector.[9]

After harmonization, available raw data sources cover over 90% of global totals across all variables. To fill remaining gaps, we first apply linear extrapolation for shorter missing periods. Usually, we use the ten-year growth rate of the first or last available year to extrapolate forward or backward, respectively. For countries with limited data over long periods or no data at all, we assign values based on regional averages of countries in the same world region, whereby countries are weighted based on the absolute value of the variable. The values for the nine residual regions are usually constructed by first harmonizing series for all 216 WID core countries, which are then aggregated to the residual regions. In the data files of this paper, the source or extrapolation method for each individual observation is recorded.

[8] More detailed information on the harmonization procedure and on source coverage by country and variable can be found in Appendix B.
[9] After harmonization, in case discrepancies exist, aggregate variables are kept fixed and subcomponents are aligned based on equal adjustments to all factors. Note that net trade is zero only with MER series, not with PPP series.

2.3. Sectoral Structure: Illustration of the 2025 Global Economy

To illustrate the basic features of our database, we start by describing global values for the year 2025.[10] In this section we focus on the macroeconomic variables, the next section then gives an overview of GHG emissions. On the economic side, we provide series both on consumption (Gross National Expenditure (GNE) and its subcomponents consumption and investment) as well as production (GDP, labour hours, productivity). Table 5 shows the structure of gross national expenditure (and disaggregated into consumption and investment) based on the eight-sector classification. Similarly, Table 6 shows the sectoral structure of global GDP and hourly productivity. Finally, Table 7 shows an excerpt of the aggregate global input-output matrix which links the expenditure and production accounting.

First, on the world level the total size of gross national expenditure (GNE) and gross domestic product (GDP) are the same. On average, per capita GNE as well as GDP amount to about 17k Euros PPP at the world level in 2025, i.e. 1.4k Euros per month. Per capita economic labour hours (i.e. excluding domestic labour) amount to about 850 hours per year, so that average productivity – as measured by hourly GDP – is approximately 20 Euros.[11] We will later discuss how these world averages vary across countries and regions, as well as our scenarios for the 21st century.

GNE is the sum of final consumption – by households and governments – as well as investment. Looking at the distribution of GNE in 2025 across sectors, around half is spent on material sector products and the other half on immaterial goods (see Table 5). Specifically, global GNE in 2025 across sectors is: 11% for Food, 20% for Housing/Construction, 15% for Manufacturing, 3% for Energy, 3% for Transport, 22% for Education/Health, 17% for Leisure/Culture and 8% for Other Services. Looking at the decomposition into investment and consumption, around three-fourths of total GNE is consumption and one-fourth investment. Consumption expenditure is dominated by Education/Health (30%) and Leisure/Culture (20%), which together make up half of today's consumption. The material sector share (42%) of consumption is smaller than in overall expenditure. Contrary, investment expenditure is dominated by material

[10] At the time of completing this study, the latest available data sources on sectoral GDP and input-output matrices refer to years 2023 or 2024 depending on the country or region. All series were updated to 2025 based on macroeconomic projections for 2025. They will be regularly updated in the future as new raw macroeconomic sources become available.

[11] Economic labour hours include all labour input used to produce goods and services included in GDP, while domestic labour hours include all other labour input. See Andreescu et al (2025) for global historical series. We discuss in section y the future evolution of economic and domestic labour time.

sectors, which make up more than 80% of investment in 2025, and mostly constitute Housing/Construction (50% of total investment) and Manufacturing (27%).[12]

Next, looking at the sectoral structure of GDP in 2025, we see some substantial differences to expenditure: 8% for Food, 14% for Housing/Construction, 15% for Manufacturing, 7% for Energy, 4% for Transport, 16% for Education/Health, 19% for Leisure/Culture and 17% for Other Services. Typically, products which are often used as intermediate inputs by other sectors show a higher share in GDP than GNE. These include both material sectors such as Energy as well as Immaterial Sectors such as Other Services (the latter includes services such as consulting, accounting, etc.). Sectors which are typically at the end of the supply chain and afterwards either consumed or invested show higher shares in GNE than GDP, e.g., Education/Health or Housing/Construction.

Combining GDP with the data on sectoral economic labour hours, we can calculate sectoral labour productivity. One can see that hourly productivities vary enormously across sectors: the Food sector stands at less than one third of average world productivity, while the energy sector is almost three times above average (see Table 6). Variations in measured productivity reflect a large diversity of factors. Differences in technology, labour composition, and capital intensity obviously play a key role. Institutional factors and disparities in bargaining power can also have a major impact on the formation of prices (and hence on measured productivity levels) for various goods and services, including agricultural products, energy, education and health services. We will later return to these issues.

Table 7 shows the sectoral linkages in the economy by presenting the intermediate consumption of all sectors as a percentage of their total output. In the input-output literature, this is known as the matrix of “technical coefficients”, or simply the A-matrix. Looking at the share of intermediate consumption in output by sector, it is clear from the 2025 A-matrix that the material footprint of "immaterial" sectors is substantially smaller than that of "material" sectors. For instance, 82% of all intermediate uses of energy in 2025 take place in material sectors. In other words, immaterial sectors (Education/Health, Leisure/Culture and Other Services) account for 52% of GDP but for only 18% of all intermediate energy uses. As we shall see later, this will play a central role for our analysis of the interplay between structural transformation and sustainability. Note, however, that the material footprint of immaterial sectors is still

[12] In national accounting, investment (gross fixed capital expenditure) entails all expenditures, which are not used up within the same accounting year. For example, buildings or machinery, which are used over several years are counted as investment.

substantial and should further be reduced to become truly "immaterial". We will later analyze in greater details the variations of the input-output matrix over time and across countries, and how it might further evolve in the future.

2.4. The Food Sector and the Transformation of Land Uses

The Food sector is particularly important for our study, given that its evolution over the next decades will be one of the main drivers of future emissions related to agriculture and land-use. Global food systems are marked by strong asymmetries in red meat consumption. Per capita beef intake is highest in North America, parts of Latin America and Oceania, and remains well above nutritional requirements in most high-income economies, while it is comparatively low in low-income regions. Ruminant meat production is particularly land- and emission-intensive, requiring large areas of pasture and generating substantial methane emissions relative to its caloric output.

Table 8 describes the global structure of land area in 2025, and Figures 2a-2c illustrate the cumulative land-use consequences of food consumption patterns. Namely, the sustained explosion of cropland and grazing land has been a primary driver of forest loss since 1800, with forest cover decreasing from about 5.2 to 4.1 billion hectares at the world level between 1800 and 2025 (including a decline of about 200 million hectares since 1990). In the meantime, agricultural land rose from 1.3 billion hectares in 1800 (including 0.8 in grazing land and 0.5 in cropland) to 4.8 billion in 2025 (including 3.2 in grazing land and 1.6 in cropland). The expansion of agricultural land was made possible both by the decline of forest cover (deforestation) and the fall of wild grasslands.[13] In turn, deforestation had a very large historical impact on CO2 emissions (ranging from circa 25%-35% of the global CO2 emissions over the past two centuries). Future dietary trajectories and reforestation plans will determine whether this trend stabilizes, reverses or continues (see section 3.4).

2.5. Sectoral Emissions: Illustration of 2025 Emission Sources

To relate our economic indicators to planetary habitability, we also harmonize data on sectoral emissions and their impact on global temperatures. We are well aware that GHG emissions are not the only indicators of planetary boundaries: ocean acidification, biodiversity loss, nitrogen and phosphorus cycles, freshwater use, and other Earth system processes also matter critically. However, data constraints and modelling

[13] The transformation of wild grasslands into agricultural land (typically grazing land in North America) played an even larger role than deforestation in terms of billions of hectares, but deforestation had a larger impact in terms of CO2 emissions and environmental damages.

complexity lead us to focus primarily on GHG emissions data in this research. We hope to extend the framework to other planetary boundaries in future work.

We distinguish between three core sources of GHG emissions: fossil fuel combustion, industrial processes, as well as agriculture and land-use change. As we will explain in detail in section 3, each requires a different modelling approach due to their distinct physical origins, sectoral attribution, and data requirements. Table 9 provides an overview of global GHG emissions in 2025 by source and GHG type.

2.5.1. Fossil Fuel Combustion

Fossil fuel combustion accounts for 39.8 Gt CO2e, or 70% of global emissions in 2025. This includes 36.2 Gt from direct combustion of coal, gas, and oil (64% of total emissions), plus an additional 3.6 Gt (6%) from methane leaking during fossil fuel extraction, processing, and distribution (often called “fugitive emissions”). These energy-related emissions are directly tied to the use of coal, gas, and oil as intermediate inputs in production and as final consumption by governments and households.

There are two distinct pathways through which fossil fuels generate emissions across the economy. First, emissions occur when fossil fuels are consumed directly by sectors and households. This happens in on-site burning within the production of a sector such as coal for industrial heat, gasoline for vehicles, or gas for heating. The type of primary energy matters enormously for emissions. For the same amount of physical energy, coal emits around 70% more than gas, and around 30% more than oil. Second, fossil fuels are burned to produce electricity in the Energy sector. In 2025, global electricity generation came mostly from coal (35% of total electricity generation) and gas (22%), followed by hydro (15%), wind (9%), solar (8%), and nuclear (9%). As we will detail in section 5.1, our decarbonization scenarios model the transition from this fossil-heavy baseline toward energy generation dominated by low-carbon sources by 2100.

The composition of direct fuel use and the share of electricity in total energy consumed determines the energy-related emissions of each sector. In standard accounting, emissions from electricity generation are attributed to the Energy sector, while emissions from direct fuel combustion are attributed to the sector that uses them. In other words, if Manufacturing or Transport electrify while the electricity generation does not become cleaner, emissions shift upstream to the Energy sector (while total emissions are more or less unchanged). Electricity represents about 24% of total final energy demand in 2025, with the remaining 76% coming from fossil fuels (69%) and low-carbon fuels such as burning of biomass (7%). Electrification levels, the amount of physical energy units bought in form of electricity rather than direct fuel, vary dramatically across sectors. Based on our data, we estimate 2025 electrification shares of 6% in Transport, 17-29% in “material” sectors such as Construction, Manufacturing, and Food, around 50% in “immaterial” sectors such as Education/Health, Leisure/Culture, and Other Services, and around 25% in Households (reflecting a mix of heating, cooking, appliances, and personal vehicles).

2.5.2. Industrial Process Emissions

Industrial process emissions account for 6.9 Gt CO2e, or 12% of global emissions in 2025. Unlike energy-related emissions, these arise from chemical reactions and industrial operations rather than fuel combustion. Major sources include cement production, chemical production, and waste treatment.

These emissions are particularly challenging to abate because they stem from the fundamental chemistry of production processes. While energy-related emissions can be eliminated through electrification and low-carbon power, industrial process emissions require either material substitution, carbon capture and storage at the point of emission, or demand reduction. We will explain how we project industrial process emissions in sections 3 and 5.

2.5.3. Agriculture and Land-Use Change

Agriculture and land-use change emissions account for 9.9 Gt CO2e, or 18% of global emissions in 2025. These are dominated by non-CO2 GHG (methane and nitrous oxide), which have much higher warming potentials than CO2 over relevant time scales. Most of these emissions come from livestock methane, agricultural soils (especially synthetic and organic fertilizers), and rice cultivation. In addition, deforestation accounts for 3.6 Gt CO2e, representing CO2 released when forests are cleared primarily to use the land for agriculture. As discussed in section 2.4, agricultural and land-use emissions are inherently linked: in our model, reforestation capacity essentially depends on reducing land used for cattle farming, which in turn depends on dietary shifts. This makes changes in food habits a key sufficiency element in our SC scenario.

2.5.4. Sectoral Attribution of Total Emissions

Having described the three physical sources of emissions, we can now allocate total emissions to the eight production sectors and households in our input-output framework.[14] Thereby, we show sectoral emissions based both on *production-based* as well as *expenditure-based* accounting.

Figure 3a presents the *production-based* sectoral breakdown for 2025, distinguishing between CO2 and other GHG. Other GHG emissions include methane, nitrogen dioxide, and fluorinated gases, which we always express in CO2 equivalents depending on their warming potential. In *production-based* accounting, emissions are attributed to the sector where they physically occur. For instance, when a coal power plant generates electricity consumed by hospitals, those emissions are allocated to the Energy sector, not to Education/Health. Similarly, when a steel mill produces steel used in automobile manufacturing, the emissions from steel production appear in Manufacturing, not under Transport.

Based on this measurement, the Energy sector accounts for the largest share of emissions (25 Gt CO2e, 44% of total), of which 18 Gt is CO2 from fossil fuel combustion in electricity generation and petroleum refining, and 7 Gt is non-CO2 emissions, primarily fugitive methane emissions from coal mining and natural gas extraction and distribution. Manufacturing emits 10 Gt CO2e (18% of total) during its production activities, of which 9 Gt is CO2 from both energy-related combustion and industrial process emissions, and 1 Gt is non-CO2 gases from waste treatment and industrial processes. The Food sector contributes 7 Gt (12%), of which only 1 Gt is CO2 from energy use in food processing and transportation, while the other 6 Gt of non-CO2 result predominately from livestock and fertilizer application.

The “immaterial” sectors (Education/Health, Leisure/Culture, Other services) together account for only 1 Gt CO2, despite representing 52% of global GDP in 2025. Education/Health and Other Services produce effectively zero direct emissions, while Leisure/Culture contributes 1 Gt CO2 from energy use in hotels, restaurants, entertainment venues, and cultural facilities. Households, at the same time, account for 6 Gt CO2e (11% of total) through direct energy consumption, including 5 Gt CO2 from residential heating and personal vehicle use, and 1 Gt of non-CO2 gases.

[14] What we describe as the “Household” sector also includes consumption and investments of governments, strictly speaking.

Emissions responsibilities differ substantially under an *expenditure-based* accounting framework. Under this approach, emissions are attributed to the final consumption or investment of goods and services, tracing all emissions embodied in the supply chain. In other words, the emissions footprint of the Education/Health sector would include not only its direct energy use (such as heating school buildings or hospitals with fossil fuels) but also the emissions generated in producing the electricity it consumes, the manufactured goods it purchases, and the transport services it relies on. Similarly, the Transport sector's footprint would encompass upstream emissions from steel production, petroleum refining, and electricity generation.

Figure 3b shows that the expenditure-based approach drastically changes the allocation of emissions across production sectors.[15] The most dramatic shift concerns the Energy sector: its production-based footprint of 25 Gt CO2e collapses to just 7 Gt CO2e under expenditure-based accounting, as its emissions are reallocated to the sectors that ultimately consume its output. Conversely, Construction grows from a negligible 1 Gt CO2e to 6 Gt CO2e, reflecting the energy- and material-intensive supply chains behind construction activity. Education/Health and Leisure/Culture similarly see their footprints grow substantially, from near zero to around 4 Gt CO2e and 5 Gt CO2e respectively once the emissions embodied in the goods and services they consume are accounted for. The emissions of the Food sector remain comparably large under both frameworks, underscoring that its emissions are more directly tied to final consumption rather than intermediate production processes.

In order to see how "material" or "immaterial" sectors really are, it is useful to express production-based and expenditure-based emissions relative to sectoral GDP. When we look at production-based emissions intensities, we find that immaterial sectors have near-zero intensities (see Figure 3c). More interestingly, when we look at expenditure-based intensities, we find that the gaps are much smaller, but that they are nevertheless substantial. Namely, Figure 3d shows that Energy and Construction are the most emissions-intensive, at 0.7 kg CO2e per euro of GDP, followed by Food and Transport, which both stand at 0.6, and Manufacturing with an intensity of 0.5. The emission intensities of what we call “immaterial” sectors are much lower – albeit clearly not zero: Education/Health and Leisure/Culture both account for 0.2 kg CO2e per euro under the consumption-based approach, and Housing Services and Other Services for 0.1 kg CO2e per euro. In other words, even taking into account the full input structure, immaterial sectors have emissions intensities that are about three to four times smaller than material sectors. This difference in emission intensities across sectors is why

[15] Emissions of the Household sector are held constant by construction.

structural transformation toward service sectors can play an important role in the climate transition. A shift in final demand composition from emission-intensive consumption such as Manufacturing toward Education/Health and Leisure/Culture not only reduces direct emissions from those sectors, but also reduces the indirect emissions generated through the inputs that they are using. As we will show in section 5, our Sustainable Convergence scenario combines energy system decarbonization with a 30% reduction in the "material sector" share of total expenditure.

2.6. Projection Framework

2.6.1. Projections of Sectoral GDP and Labour Hours

In practice, we observe the A-matrix $A_{ct,}$ similar to the 2025 global matrix depicted on Table 7, for all countries-years over the period 1970-2025, and we will be making assumptions about the future evolution of A-matrices at the global level (see the discussion in sections 3 and 5 below). By definition, A-matrices allow us to make the bridge between the sectoral structure of GDP (gross domestic product, defined as the sum of sectoral value-added) and GNE (gross national expenditure, defined as the sum of sectoral final consumption expenditure (by households and governments) and investment expenditure, also referred to as "final demand" in national accounts terminology)[16], via the following matrix equation:[17]

$$GDP_{ict} = (I - A_{ict})^{-1} \, GDE_{ict} \qquad (2)$$

With:
GDP_{ict} = vector of sectoral value-added for sector i, country c, and year t
A_{ict} = A-matrix
$GDE_{ict} = GNE_{ict} + TB_{ict}$ = vector of sectoral gross domestic expenditure
GNE_{ict} = vector of sectoral gross national expenditure
$TB_{ict} = X_{ict} – M_{ict}$ = vector of sectoral trade balance
X_{ict}, M_{ict} = vectors of sectoral exports and imports

[16] Government final consumption expenditure corresponds to the goods and services provided for free (or at prices significantly below costs, typically covering less than half of the costs) to households by the government, such as education or health or national defense. National accounts distinguish between individual consumption expenditure provided by the government (i.e. when we can assign the benefit of public services to one or several households in particular, e.g. for education and health) and collective consumption expenditure provided by the government (as opposed to public health service for example) they benefit the community in general. In this paper, we are primarily interested in total sectoral final consumption expenditure (household and government).

[17]Vectors and matrices referred to in this equation use the 9-sector classification described on Table 7.

The resulting sectoral GDP from equation (2) relates to sectoral economic labour hours through the sectoral labour productivity:

$$H_{ict} = GDP_{ict} / P_{ict} \quad (3)$$

With:
H_{ict} = vector of total work hours in sector i, country c, and year t
P_{ict} = vector sectoral productivity expressed as euros of GDP produced per hour

2.6.2. Projections of Energy- and Industry-Related Emissions

Finally, the input-output framework also allows us to determine the energy used by each sector and GNE and the associated emissions. First, total sectoral output is the sum of a sector's value-added and inputs from all other sectors used in production:

$$Q_{ict} = GDP_{ict} + \sum_j IC_{ijct} \quad (4)$$

With:
Q_{ict} = vector of gross sectoral outputs for sector i, country c, and year t
IC_{ijct} = intermediate consumption input from sector j to sector i.

To obtain energy-related emissions, the sectoral output vector can be multiplied by sectoral energy intensity coefficients. These input/output coefficients are observable in the A-Matrix. We thereby use supplementary data to extend the A-matrix and GNE to differentiate between specific energy types (i.e. different primary fuels, denoted f). Together with the energy used in GNE, this results in total energy demand by type:

$$E_{fict} = e_{fict}\, Q_{fict} + E_{fict}^{GNE} \quad (5)$$

With:
E_{fict} = vector of energy demand by energy types f, sector i, country c, and year t
e_{fict} = vector of energy inputs by energy types per unit of output
Q_{fict} = vector of gross sectoral outputs
E_{fict}^{GNE} = energy in GNE

In section 5, we explain in more detail how we distinguish between five main energy inputs (e_{fct}): coal, gas, oil, low-carbon fuels, and electricity. We also discuss the evolution of those coefficients over time depending on our assumptions about fuel switching and electrification, as well as energy efficiency improvements.

Because all monetary values in our framework are expressed in constant 2025 prices, the energy intensity coefficients e_{ict} represent physical quantities valued at 2025 relative prices. For instance, if coal costs EUR 100/ton per joule of energy and electricity EUR 1000/ton per joule of energy in 2025, these relative prices remain fixed throughout our projection period. This means that when we change the energy mix (e.g., replacing coal with electricity), we are changing the physical composition of energy inputs. The projected monetary value of total energy inputs must then adjust accordingly, reflecting the fixed relative prices. The key implication is that we abstract from future relative price changes between energy sources. In reality, if low-carbon energy becomes dramatically cheaper than fossil fuels, the economic cost of the energy transition would be lower than our constant-cost framework implies. However, the physical energy requirements and associated emissions that we project remain invariant to price assumptions and thereby valid.

Having projected total economy energy demand, energy-related emissions can then be calculated by applying fuel-specific emission factors (for simplicity of notation, we drop sectors from the equation):

$$EM_{fct}^{Energy} = E_{fct} r_{fct} \tag{6}$$

With:
EM_{fct}^{Energy} = vector of sectoral emissions by energy input for country c and year t
E_{fct} = vector of sectoral energy demand by energy type
r_{fct} = vector of emission intensities of different energy types

Our vector of emission intensities distinguishes between different types of GHGs, notably carbon dioxide (CO2), nitrous oxide, methane, and fluorinated gases. Like energy intensities, emission intensities are expressed in monetary terms (emissions per euro of output). However, since we run our projections in constant 2025 prices, this is equivalent to applying physical emission intensities.

The emission factors r_{fct} for fossil fuels (coal, gas, oil) and low-carbon fuels remain constant over time, reflecting their inherent carbon content: A ton of coal combusted in 2025 produces the same CO2e as a ton combusted in 2100.[18]

Beyond energy-related emissions, we also track industrial process emissions. We link those emissions directly to the output of the two sectors in which they occur in our framework: Manufacturing and Water/Waste, which we isolate as one subcategory of the initial aggregated macroeconomic Energy sector.

$$EM_{ct}^{Industrial\ processes} = Q_{ct}a_{ct} \tag{7}$$

With:
$EM_{ct}^{Industrial\ processes}$ = vector of sectoral industrial emissions for country c and year t
Q_{ct} = vector of gross sectoral outputs (of Manufacturing and Water/Waste sectors)
a_{ct} = vector of emission intensities of industrial processes (of Manufacturing and Water/Waste sectors)

2.6.3. Projections of Emissions from Land-Use Change and Agriculture

In order to model the change in food patterns and its emission impacts – one of the key sufficiency elements of our Sustainable Convergence scenario – we project forest area, cropland, and grazing land explicitly. In the projections, the extent of reforestation depends on the agricultural output as well as the food consumption habit (cattle-intensive or plant-intensive), such that sufficiency is a key determinant of land-use emissions. Specifically, cropland expansion is driven by population growth, agricultural output, and relative yield assumptions between organic and non-organic farming. Forest area follows either observed trend continuation (constant food patterns) or a policy-driven reforestation path (substantial change in food patterns). Grazing land adjusts endogenously to reconcile cropland requirements and forest targets, which implies a change in food habits.[19] Our model is described in detail in Appendix C.

[18] Note that the emission factor of electricity is 0 by definition at the point of use: no emissions are emitted when a factory runs an electric motor or a household uses an electric heater. However, emissions are generated upstream during electricity generation as soon as power comes from fossil fuels. As explained above, these emissions occur within the Energy sector itself and are captured through the Energy sector's own fuel inputs in the A-matrix.

[19] When grazing land contraction is insufficient to accommodate additional cropland needs, the residual adjustment is implicitly drawn from other non-forest, non-agricultural land. In our projections, this residual source accounts for a relatively small share of cropland expansion by 2100 (approximately 11%) and remains well within the globally available area of such land. While future work will assess the associated carbon implications of these conversions, their expected contribution to CO2 emissions is modest relative to the forest-area changes explicitly modelled here.

In our model, non-CO2 emissions of the Food sector evolve endogenously as a function of land projections: reduced demand for grazing land is associated with reduced emissions from cattle digestion (and other non-CO2 agricultural emissions). We thereby assume that non-CO2 agricultural emissions are reduced at a rate x=50% faster than implied by land contraction alone, reflecting improvements in feed quality, manure management, and livestock productivity. Assuming x=0% would increase overall agriculture emissions over 2025-2100 in our most optimistic scenario by 9%.

Beyond the two key scenarios – constant food patterns at large agricultural output growth (as in Productivist Convergence without sufficiency) and sustainable food patterns with limited agricultural output growth (as in Sustainable Convergence with sufficiency) – we express the agricultural land use and corresponding emissions as a function of output of the Food sector and habit change, resulting in a continuum of agricultural and land-use emissions between the two key scenarios, which we benchmark as “worst” and “best” cases.[20]

2.6.4. Translating Emissions Projections to Temperature Rise

We simulate the temperature response to CO2, methane, nitrous oxide, and fluorinated gas using the FaIR reduced-complexity climate model, used in the IPCC AR6. FaIR links emissions to atmospheric concentrations, radiative forcing, and global mean temperature over time (Leach et al., 2021).[21]

It represents carbon-cycle uptake and gas lifetimes through impulse-response functions, applies gas-specific radiative efficiencies, and computes temperature using a calibrated energy-balance framework. This structure allows scenario-specific temperature outcomes to be estimated efficiently while remaining consistent with physical climate constraints.

We construct a dedicated interface to feed FaIR with the emissions pathways generated by our scenarios.[22] We set a benchmark temperature of 1.4°C above the pre-industrial average. Methane and nitrous oxide are modelled dynamically within FaIR using gas-specific lifetimes and radiative efficiencies. GWP100 values are used

[20] Negative GHG emissions from reforestation are capped at the ambitious policy-driven reforestation path, which results in forest coverage in the magnitude of the state of the world in 1900. Thus, scenarios with smaller GDP per capita (e.g. 30k euros) and sufficiency, which have a smaller agricultural output, do not have larger negative emissions but have smaller agricultural non-CO2 emissions than our main scenario.
[21] Note that AR6 uses an earlier version of FAiR, i.e. v1.6.
[22] See the “GJP Temperature App” in the replication package.

for reporting comparability, but temperature projections are derived from the time-evolving radiative forcing of each gas rather than from static CO2-equivalent aggregation.

We apply a central Transient Climate Response to Cumulative Emissions (TCRE) of 0.45°C per 1000 $GtCO_2$, consistent with IPCC AR6, to translate cumulative CO2 emissions into carbon-budget metrics for interpretative purposes. The TCRE is not used to compute temperature trajectories; temperature projections are derived endogenously from FaIR.

All temperature projections are subject to parametric uncertainty in climate sensitivity, carbon-cycle response, and aerosol forcing. We use the AR6-calibrated FaIR parameter ensemble and report median temperature responses unless otherwise stated. Sensitivity analysis propagates the calibrated parameter ensemble through the model and reports the 5th–95th percentile range of resulting temperature outcomes.

3. Modelling Global Convergence 2026-2100: Toward Sustainable Prosperity

We now describe the main assumptions of our different scenarios. We start with the macroeconomic assumptions of our benchmark Sustainable Convergence (SC) scenario. We first discuss the projected trajectories for aggregate GDP, labour hours, and productivity, before proceeding with the projections on population, the sectoral shift from material to immaterial sectors in expenditure, changes in food habits, and the structure of the A-matrix and trade flows. Next, we discuss the patterns of sectoral productivities and labour hours and finally the modelled post-2100 steady state of the economy. Structural transformation takes three main forms in our benchmark scenario: first, a large reduction on economic labour hours (so as to limit the overall growth of production, both in material and immaterial sectors); second, the sectoral reallocation of consumption and production (so as to reduce the relative importance of material vs immaterial sectors); third, the shift in food habits toward reduced consumption of animal products, in particular red meat.

3.1. GDP, Labour Hours & Productivity: The Sustainable Prosperity Framework

In the benchmark Sustainable Convergence (SC) scenario, all countries reach 60k euros in per capita GDP in 2100 (using fixed 2025 PPP prices), close to today's levels in the world's richest countries, but with a different consumption bundle (less material goods, more education and health). In our benchmark scenario, we assume a 30%

reduction of the share of material sectors in final consumption and investment expenditure at the world level between 2025 and 2100, and a 40% rise of the share of education/health within immaterial sectors. We also analyze alternative sustainable development scenarios with lower GDP targets (15k, 30k or 45k euros; see Figures 1a-1c), as well as Productivist Convergence (PC) scenarios with higher GDP targets (120k) and Persistent Inequality (PI) scenarios, and describe their impact on planetary habitability as compared to the 60k euros benchmark convergence scenario. Similarly, we study how much the material-vs-immaterial parameters matter for planetary habitability as compared the GDP-target parameter.

Several points are worth stressing about our framework. First, the 60k benchmark target for 2100 has been chosen because it is approximately equal to the level currently observed in the world's richest countries. According to our estimates, per capita GDP is equal to 42.8k in Europe (including 60.1k in Denmark and 70.9k in Norway) and 55.5k in North America/Oceania (including 59.3k in the USA) in 2025. In other words, we are asking in our benchmark scenario whether it is possible for all world countries to reach the income level currently attained by Denmark and the USA and we analyze the consequences for planetary habitability. From the viewpoint of the richest countries, this means that per capita GDP will remain approximatively at the same level in PPP terms over the 2025-2100 (or decline a little bit in some rare cases).[23] Note that this does not imply that the well-being of these countries is scheduled to stagnate in the 21st century according to the SC scenario. Taking into account the value of additional free time (leisure) and the value of planetary habitability, even the richest countries of 2025 will actually enjoy a substantial rise in comprehensive well-being indicators between 2025 and 2100 (see section 7).

Next, according to our benchmark scenario, the 60k euros target for 2100 comes as the combination of large sustained productivity growth and a significant reduction in economic labour hours. In our baseline projections, we assume that hourly GDP converges toward 125 euros in all countries by 2100 (see Figure 4), and that average economic labour hours per employed individual drop from about 2100 hours to 1000 hours at the world level between 2025 and 2100 (see Figure 5). Following Andreescu et al (2025), we also assume that all countries converge toward full gender equality in

[23] In our set of 48 main countries (see Table 3), the only two countries with per capita GDP above 60k euros in 2025 are Denmark (60.1k) and most importantly Norway (70.9k). Looking at the extended set of 216 core countries used in WID, there are many other small countries and jurisdictions – including island states and tax havens – with per capita GDP above 60k. See Gomez-Carrera et al (2024).

economic labour hours – including similar employment rates for men and women – and domestic labour hours (see Figure 6).[24]

There are two broad reasons why individual countries and the world as a whole might decide to reduce labour hours in the coming decades. First, countries in the past have generally used a significant part of their long-run productivity gains to enjoy more free time (leisure) rather than to maximize consumption. Next, this can happen because the threats to planetary habitability provide an additional rationale for reducing labour hours and limiting material footprint in the future. According to our benchmark projections, 44% of global productivity gains will be used to reduce labour hours over the 2025-2100, which is only slightly more ambitious than what happened in the past: 32% on average over the 1800-2025 period, including 40% over the 1860-1980 period, which corresponds to the peak period of working-class mobilization for labour time reduction (see Table 10 based on Andreescu et al, 2025).

Regarding productivity growth rates, the assumptions in our benchmark trajectory are also in the range of historical experiences. The convergence of all countries to hourly productivities equal to 125 euros by 2100 does require substantial annual productivity growth rates in the world's poorest regions between 2025 and 2100 (as much as 4.5% per year in Subsaharan Africa). However, these growth rates are not larger than those observed in East Asia over the 1990-2025 period (4.7% per year). More generally, we observe annual productivity growth rates around 4%-5% per year (or more) in all world regions that have gone through accelerated productivity convergence in the past, whether we consider the case of East Asia in 1990-2025 or Europe in 1950-1990 (see Table 11).[25]

Needless to say, the fact that our benchmark projections for labour hours and productivity are consistent with past experiences does not imply that they are easy to implement. They require specific sets of policies and institutions (including ambitious labour hours legislation and massive investment in education, health and

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[24] In particular, we assume that the employment rates of working-age men and women (15-to-64 year-old) converge toward 80% in all countries by 2100. While this stands in the continuation of the trends already observed between 1950 and 2025 in many world regions (especially the world's richest regions: Europe, North America/Oceania, East Asia, and to a lesser extent Latin America, Russia/Central Asia and Subsaharan Africa), this would require a very substantial move toward gender equality in lagging regions like Middle East/North Africa and South and South-East Asia. See Appendix Figures E1c-E1h.

[25] At the country-level, one can observe even higher levels of productivity growth rates over long periods during catch-up phases, typically in the 5%-7% range: 5.5% in Japan 1950-1990, 6.5% in Korea 1950-1990, 5.8% for Taïwan 1950-1990, 5.4% for Spain 1950-1990, 7.0% for China 1990-2025. Prolonged productivity growth rates in the 4%-5% range are even more common: 4.8% in Germany 1950-1990, 4.0% for France 1950-1990, 4.2% for Italy 1950-1990, 4.1% for Netherlands 1950-1990, 4.1% in India 1990-2025, etc. See Appendix Table F2b.

infrastructures), and most importantly specific sociopolitical coalitions supporting these policies. We will later return to these issues about implementation.

3.2. Population: Early Stabilization Thanks to Global Convergence

One way in which accelerated convergence in living standard between countries can contribute to sustainability is that it can speed up the demographic transition in low-income countries. According to the latest UN projections (medium scenario), world population is scheduled to rise from about 8.2 billion in 2025 to 10.3 billion around 2080, before starting to decline slightly to about 10.2 billion by 2100. Given that we assume accelerated economic convergence, we instead choose to adopt the "ABR decline scenario" scenario by the UN population division, according to which world population is scheduled to peak at about 9.8 billion around 2070 and decline to 9.4 billion by 2100.[26] In effect, our benchmark projections are intermediate between the UN medium population scenario and the SSP1 demographic scenario used in many IPCC reports (see Figure 7).[27]

Irrespective of the uncertainties about demographic projections, several points are worth stressing. First, in all scenarios, the population of the world's poorest countries is scheduled to rise enormously. In particular, in our benchmark scenario, the population of Subsaharan Africa rises about from 1.3 billion in 2025 to approximately 2.9 billion in 2100 (see Figure 8).[28] The population of Subsaharan Africa would rise even more in the absence of economic convergence, which is likely to lead to unprecedented migration pressures.

Next, in all scenarios, the world is scheduled to reach zero or slightly negative population growth by the end of the 21st century, namely between -0.1% and -0.2% per year over the 2080-2100 period according to our benchmark scenario. This

[26]The UN "accelerated decline of adolescent birth rate" (ABR) scenario assumes unusually fast decline of adolescent birth rates beginning in 2025. We take as given the country-level population trajectories described in the UN ABR scenario. We make only one small change to age structures, namely we assume that all countries converge to the same fraction of working-age population (60%) between 2050 and 2100 (as opposed to a world average equal to 59% in raw series in 2100, with most countries in the 56%-62% range), so as to avoid country asymmetries in working time in 2100. The other possibility would be to assume higher per-working-age-individual labour hours in countries with smaller working-age population, so as to obtain similar per-capita labor hours and per capita GDP in all countries in 2100. In practice this makes very little difference.

[27] See IPCC 2023 (AR5). SSP projections rely on their own demographic assumptions and appear to be more restrictive (population-wise) than the most restrictive UN projections. The justification for this significant divergence with UN projections is not entirely clear. Our projections are more conservative: they follow directly from UN projections and are potentially more realistic.

[28] Subsaharan African population reaches 3.5 billion by 2100 according to the UN medium scenario and 2.2 billion in the IPCC1 scenario. The rise between 2025 and 2100 is huge in all cases.

corresponds to a major transformation of the structure of economic growth. Over the past two centuries, world population growth has been almost as large as per capita GDP growth, resulting in a very large contribution to aggregate GDP growth. Namely, real aggregate GDP rose at a rate of 2.2% per year between 1800 and 2025, including 0.9% for population growth and 1.3% for per capital GDP growth.[29] In contrast, by the end of the 21st century, most or all of aggregate GDP growth will come from per capita GDP growth, and population will decrease aggregate GDP growth (see Table 12). Also, note that per capita GDP growth is scheduled to decline to less than 1% per year in 2080-2100 in our benchmark scenario, due to both the end of catch-up effects (all countries are about to converge to the same productivity level) and the shift from material to immaterial sectors (the latter being characterized by slower productivity growth; see below).

3.3. Sectoral Transformation: Priority to Immaterial Growth

The key objective of the Sustainable Convergence scenario is to reconcile inclusive prosperity – all countries reach the 60k target by 2100 – with sustainability. This likely requires a major shift from material to immaterial sectors, both for consumption and investment expenditure. We start with the overall balance between final consumption and investment expenditure. Then, we look specifically at the changing composition of investment, consumption, and finally total expenditure.

3.3.1. Investment Expenditure and the Evolution of the Capital Stock

In our benchmark Sustainable Convergence scenario, we project that global investment expenditure, which has increased from 26% of global GDP in 1970 to 27% in 2025, will rise to about 31% by 2050, before declining to around 20% by 2100 (see Figure 9).[30] The investment peak at mid-century is partly driven by climate investments (mitigation and adaptation), particularly by investment needs in the low-carbon energy sector and infrastructure in catching-up regions like Subsaharan Africa and South & South-East Asia.[31] This leads to a large rise in the total capital stock (relative to GDP) in the coming three decades (see Figure 10). The projected investment decline at the

[29] This corresponds to a multiplication by 8.2 of total population (from 1.0 billion to 8.2 billion) and by 17.8 of per capita GDP (from 950 Euros to 16 870 Euros) between 1800 and 2025.

[30] Available national accounts series on investment expenditure do not always offer a decomposition between housing and other capital investment. The breakdown reported on Figure 8 was estimated using the investment flows decomposition available for some countries and the capital stock decomposition available for all countries. See Bauluz et al (2025) and online replication package..

[31] See Appendix Figure J0d. Depending on the target convergence speed and inequality dynamics, one might favour an alternative secanrio including a higher investment peak in 2030-2060 (say around 30-35% of global GDP).

end of the century is due to growth slowdown. That is, with lower aggregate GDP growth rates, less investment is needed to maintain a given level of capital stock (relative to GDP), both in terms of housing and other capital needs. In spite of declining projected investment rates, our simulations show that the world capital stock will keep rising at the end of the century and stabilize around 600% of GDP in all countries and at the world level by 2100 (see Figure 10).

Several points are worth stressing about these projections. First, the projected rise of the global capital/GDP ratio over the 2025-2100 period is substantial but less massive than the increase observed between 1970 and 2025. It should be noted that the 1970-2025 rise is mostly due to rising relative asset prices (see Bauluz et al (2025)).[32] In contrast, we do not assume any substantial asset price effect over the 2025-2100 period: the projected rise of the global capital/GDP ratio depicted on Figure 10 follows for the most part from the accumulation of the real investment flows.[33]

Next, we project consumption of fixed capital (CFC) to stabilize around 16% of world GDP over the 2025-2100 period (see Figure 11). Note that the rise of CFC observed between 1970 and 2025 – from 12% to 16% of world GDP – is very substantial but less massive than the rise in the capital stock. This means, measured depreciation rates have declined over this period (again largely due to rising asset prices), and we project these depreciation rates – estimated separately for housing and other capital assets – to stabilize over the 2025-2100 period (see Figure 12).

It should also be noted that the notions of investment expenditure and capital stock which we consider here correspond to national accounts concepts (SNA 2008) and are relatively restrictive. In particular, education and health expenditure is treated as consumption expenditure (and not as investment) in official national accounts guidelines, in spite of the fact that human capital expenditure is well known to be one of the key factors behind productivity growth and global convergence (see Bharti et al., 2025). Our projected rise of human capital expenditure over the 2025-2100 period is substantially larger than the projected decline in investment expenditure (in the national accounts sense). In section 7, we will further discuss the total financing needs

[32] The rise of asset prices – both housing prices and stock prices – relative to other prices can itself be accounted for by a diversity of factors, including agglomeration effects, policy and regulatory changes, and rising bargaining power of capital owners vis-a-vis other stakeholders.
[33] More precisely, we assume counteracting relative asset price effects in the various world regions (declining in the richest regions and rising in the poorest regions) so that regional asset prices converge by 2100 and world asset prices follow approximately the same average evolution as other prices over the 2025-2100 period. These assumptions are irrelevant for the analysis of expenditure and production trajectories and their impact on carbon emissions and planetary habitability, but they have important consequences for between-countries and within-countries inequality dynamics.

associated to capital investment (including climate investment and other investment) and human capital expenditure associated to the Sustainable Convergence scenario

Finally, although investment expenditure – in the national accounts definition – is a fairly restrictive concept, it is worth stressing that it does include immaterial components (such as research and development), and most importantly that the immaterial share has risen over time. Back in 1970, 92% of investment expenditure took the form of goods and services produced by material sectors, stemming for the most part from the construction and manufacturing sectors. By 2025, the share of material sectors in total investment expenditure has declined to 81% according to our database. In the benchmark scenario, we project the dematerialization of investment expenditure to accelerate in the future such that the material share will further fall to 56% by 2100, i.e. a reduction of 30% between 2025 and 2100 (see Figure 13). In practice, immaterial investment is particularly strong in the sector of other services, where a large part of research and development activities are located (including computing and data services, architecture, etc.). Historically, investment expenditure has long been concentrated in material sectors, especially construction and manufacturing. In effect, the share of investment expenditure in total sectoral expenditure (investment + final consumption) has always been around 95-100% in the construction sector, 50% in the manufacturing sector (i.e. manufacturing goods used for investment purposes are approximately as large as those used for final consumption), and less than 10% in most other sectors, with the important exception of other services, where the investment share rose from 20% to 30% between 1970 and 2025 and is further projected to rise to 45-50% by 2100 (see Figure 14). In our benchmark scenario, construction and manufacturing still represent a very large part of aggregate investment expenditure by 2100, but other sectors combined are projected to make almost half of the total (see Figure 15).

3.3.2. The Uneasy Decline of Material Consumption Expenditure

We now move to final consumption expenditure, which is the larger expenditure component (generally around 70-80%, vs. 20-30% for investment). A striking finding from our historic database is that there was actually no decline in the share of material sectors in final consumption expenditure over the 1970-2025 period. At the global level, the share of material sectors actually rose slightly from 40% to 42% between 1970 and 2025, and we observe a similar stability (or small rise) in most regions. In contrast, we assume in our benchmark scenario a 30% reduction in the material share of final consumption expenditure at the world level between 2025 and 2100, and a 40% rise in the share of Education/Health within immaterial sectors (see Figures 16-17).

Looking at total expenditure (i.e. gross national expenditure, the sum of final consumption and investment expenditure), we find that the share of material sectors has been stable at 53% of GNE between 1970 and 2025, due to the fact that the (small) rise of the material consumption share was compensated by the (small) decline in the material investment share. In contrast, we assume in our benchmark scenario a 30% reduction of the material share of GNE (and a 40% rise in the share of education/health in immaterial sectors) at the global level between 2025 and 2100 (see Figure 18).

The stability of the share of material sectors in GNE between 1970 and 2025 is a striking result which can be explained as follows. First and foremost, it should be emphasized that this result holds using constant relative prices (namely, constant prices in 2025 Euros PPP).[34] If we instead use current prices, then the share of material sectors actually declined substantially, namely from 60% to 53% of global GNE between 1970 and 2025.[35] The intuition is the following. Because they experience faster technical progress, the relative price of the goods produced by material sectors tends to fall over time in comparison to immaterial sectors. This so-called "Baumol effect" is particularly strong for the relative price of manufacturing outputs (and to a lesser extent food products).[36] The point however is that falling relative prices contribute to maintain high and rising demand (and to postpone satiation effects for these goods), so that at the end of the day the share of material sectors in final consumption expenditure does not decline in volume terms (which is what matters for material footprint and planetary habitability), or even rises a little bit. In other words, there is no reason to expect market-driven economic development to lead to a major shift from material to immaterial sectors. Past development patterns rather seem to be characterized by an addition – rather than a substitution – of expenditure patterns: new forms of immaterial expenditure develop in multiple sectors (Education/Health, Leisure/Culture, Other Services), but older forms of material expenditure keep rising in other sectors (Food, Housing/Construction, Manufacturing, Energy, Transport), and both categories of expenditure appear to be rising at approximately the same speed at the global level.[37]

[34] The result also holds with 1970 constant prices or any other year.
[35] See Appendix Figure H0s.
[36] See section 8 and Figures 53a-53b below. See also Odersky (2025) for a more detailed analysis of « Baumol effects » vs. « Engels effects ».
[37] This is in some way comparable to the logic developed by Fressoz (2024), according to whom the development of energy systems is characterized by the addition of energy sources rather than by a process of substitution.

This finding also implies that the sharp dematerialization associated to our benchmark scenario over the 2025-2100 period is unlikely to come spontaneously as a market outcome. One solution would be to raise the price of material goods via a form of carbon tax, so as to reduce the share of material sectors in total consumption. However, such a solution – advocated by many economists due to its market-friendliness – is likely to entail major negative distributional consequences and might not lead to the desired outcome. We will later discuss the various policy combinations which could be mobilized to implement the Sustainable Convergence scenario (see section 8).

3.4. Changes in Food Habits and Land-Use Patterns

Two land-use scenarios are considered for 2025–2100. Before we present these two scenarios, one important fact to have in mind is that the very large deforestation which took place in the long-run, with a decline of global forest cover from 5.2 to 4.1 billion hectares between 1800 and 2025 (see section 2, Figures 2a-2c), did continue in recent decades, and is likely to continue in the future if no major policy change is implemented. According to available evidence, the decline in global forest cover observed between 1990 and 2025 amounts to about 200 million hectares, and there is no sign that this is decelerating in any significant manner. This simple fact is sometimes obscured in public debate by the fact that most regions in the Global North (East Asia, Europe, North America, Russia) have actually experienced moderate reforestation in recent decades.[38] However, the point is that the continued deforestation that has been happening in the Global South (especially in Latin America, and to a lesser extent in Sub-Saharan Africa and South & South-East Asia) was a lot larger, resulting into a net negative impact of about 200 million hectares for global forest cover (see Figure 19). Two additional points should be emphasized. First, the areas which are currently under deforestation include much denser forests with stronger CO_2 absorption capacities per hectare (two to three times larger) than the areas under partial reforestation. Next, the continued deforestation going on in the Global South is largely serving the international markets (including in particular countries in the Global North) via increased production of meat and other food products and natural resources.

According to our Sustainable Convergence scenario, a complete ban on deforestation will be imposed in 2030 and a large reforestation plan will allow global forest cover to

[38] This is partly due to reforestation efforts and/or the rise of agroforestry business, but also in some cases to natural forest regrowth (in line with decline in agricultural sector and rural peasantry).

gradually rise from about 4.1 billion hectares in 2025 to 4.8 billion by 2100, i.e. approximately the same level as in 1900 (see Figure 20). In contrast, in the Productivist Convergence and Persistent Inequality scenarios, we assume constant food patterns, and deforestation is expected to continue at the same speed as in recent decades, so that global forest cover will reach about 3.6 billion by 2100.

To be more precise, in the SC scenario, we model a substantial decrease in the consumption of animal products, in particular red meat, and introduce an explicit reforestation trajectory in tropical regions. Figure 21 shows what this implies for global land use. Global forest cover increases by 16% between 2025 and 2100, particularly driven by reforestation in tropical regions, where forests are projected to grow at annual rates of 0.3% between 2030 and 2060, and 0.5% from 2060 to 2100 (Figure 22a). These growth rates are conservative relative to observed reforestation episodes. Cropland is projected to expand in the next decades, but much less than in the scenario of constant food patterns, assuming higher land efficiency (Figure 22b). Lastly, global grazing land is reduced by around 25% over 2025-2100 (with a 42% drop in Latin America), reflecting the sharp decline in red meat consumption (Figure 22c). Given this reduction in grazing land, and assuming that all regions converge in terms of red meat consumption by 2100, we find that North American per capita red meat consumption would need to fall by a factor of around 4.5 by 2100, and Western European consumption by around 2.5.

In the scenario of constant food patterns (PC and PI scenarios), forest, grazing land and cropland evolve according to the continuation of observed trends over 2000–2025 period (Figure 23). Under these observed trends, forest area declines sharply in tropical regions. In Latin America and Sub-Saharan Africa, forest area falls by 37% and 52% between 2020 and 2100, respectively. At the global level, forests decline by 14%, corresponding to a reduction of approximately 570 million hectares over 2025–2100 (Figure 24a). Grazing land increases in some tropical regions but declines globally by about 9% (Figure 24b). Cropland expands strongly (by roughly 77% globally in trend continuation) in those regions (Figure 24c). These projections are direct extensions of the 2000–2025 trend.

We should make clear that the radical change in land-use patterns proposed under the Sustainable Convergence scenario includes large environmental benefits for the planet as a whole but also entails significant economic costs, especially for the producing regions (particularly Latin America). In our view, the only way to implement such a scenario is to have some form of global fund in order to compensate the countries and regions which accept to forego these economic benefits. We return in sections 7-8 to the discussion of the far-ranging institutional and distributional changes associated to the Sustainable Convergence scenario.

3.5. From Expenditure to Production: Input-Output Matrices and Trade Flows

The general logic behind our simulations of the global sectoral structure of expenditure and production over the 2025-2100 period can be summarized as follows. First, we set the target structure of gross national expenditure in 2100, which is characterized by two main sets of parameters: the total economy target parameter for per capita GNE and GDP (60k euros in the benchmark scenario); and the material-vs-immaterial-sectoral parameters (30% reduction in the share of material sectors, and 40% rise in the share of education/health within immaterial sectors). We then set the speed at which each country converges to the same level and structure of per capita GNE in 2100. In our benchmark scenario, most of the convergence is achieved by 2080, in line with plausible assumptions on catch-up effects and the productivity impact of human capital expenditure.[39] Once each country-specific GNE trajectory over the 2025-2100 is set, the next step is to estimate for each country-year the structure of sectoral GDP using equation (2) (see section 2.6). To make such projections at the country level, two crucial sets of parameters need to be determined: A-matrices and trade flows.

Regarding the input-output structure of the economy, our benchmark assumption is that each country linearly converges between 2025 and 2100 to the same A-matrix, namely the A-matrix observed at the world level in 2025, with the exception of the energy-related technical coefficients, which we model separately based on assumptions on decarbonization (section 5).[40] This modelling assumption can be justified by the fact that A-matrices vary relatively little over time and across countries. The general trend over the 1970-2025 is the input intensity of production tends to rise, but the trend is relatively slow. For instance, at the world level, intermediate inputs made on average 46% of total output in 1970 (all sectors combined), and this global input-output ratio rose to 52% by 2025 in current prices, with limited variations across countries. In our benchmark simulations, we assume that this ratio will converge to 52% in all countries by 2100 (see Figure 25). We also observe that the input-output

[39] See Bharti et al (2026). See also Bothe et al (2026) for estimates of the share of cross-country convergence which can be accounted for by the rise in human capital expenditure.

[40] More precisely, to capture the energy transition, physical energy requirements per unit of output are kept constant (subject to efficiency improvements), but the energy mix is allowed to shift across fuel types. This implies that for each purchasing sector, the coefficients recording energy inputs per unit of output adjust in monetary terms as the price-weighted composition of energy inputs shifts, even when the underlying physical energy intensity remains stable.

ratio has increased in all sectors between 1970 and 2025, but with a very stable ranking between sectors. Namely, material sectors like Manufacturing, Construction, Food and Energy have always been the most input-intensive (with input-output ratios around 60-70% in 2025), while immaterial sectors like Education/Health, Leisure/Culture and Other Services have always been much less input-intensive (with input-output ratios around 30-40% in 2025). In our benchmark simulations, we assume that each country converges by 2100 to the world average observed in 2025 in each sector (see Figure 26).

Finally, it is also interesting to look at the share of each sector's output that is used as an intermediate input by other sectors (as opposed to the share that is used as final consumption expenditure or investment expenditure). We again observe very stable rankings between sectors. E.g. this share has always been highest in Energy (over 80% in 2025), followed by Transport, Other Services and Manufacturing (65-75%), Food and Leisure/Culture (45-50%), Construction and Housing Services (20-25%) and Education/Health (less than 10%). In our benchmark simulations, we also assume that each country converges by 2100 to the world average observed in 2025 in each sector (see Figure 27). The modelling choice of a common 2100 A-matrix across all countries arises from the general convergence-based approach of our study and the above-described observation that in general input-output structures are rather dominated by technological differences, which we model to converge in all countries, than specific geographic or regional factors. Nonetheless, in the future other modelling choices including scenarios regionally constant and with rising and declining input intensities should be studied (see concluding comments in section 9).

Regarding the overall level and composition of trade flows, we project that the export/output ratio will remain at the same level in Manufacturing and Food sectors in 2100 as what it is in the world in 2025. However, given that the share of these sectors in total output is scheduled to decline in our benchmark scenario, this also implies that manufacturing and food trade is scheduled to decline as a fraction of world GDP. International transport is also projected to decline, and even more so for energy trade, given the turn to renewable energy. This is partly compensated by the rise of trade in immaterial sectors, so that in our benchmark scenario we project world trade to be almost as large as a fraction of world GDP in 2100 as in 2025 (see Figure 28).[41]

[41] In line the large rise observed in 1970-2025, we project the export/output ratio to be multiplied by 1.5 between 2025 and 2100. We assume the export/output ratio to be constant in leisure/culture, and to rise to the level of leisure/culture in education/health (a sector where international trade has been negligible so far). Trade in education/health (and other immaterial services) can take the form of online services or temporary physical presence in the country importing these services.

Regarding the pattern of trade surpluses and deficits, our benchmark assumption is that all countries will be in a situation of trade balance in all sectors by 2100: they will all have the same production and expenditure structure by sector, as well as the same level of imports and exports within each sector.[42] However, during the 2025-2100 transition period we assume that the convergence process will involve substantial trade deficits in developing countries, particularly in Sub-Saharan Africa and South and South-East Asia (see Figures 29 and 30a-30f). In effect, these trade deficits are the counterpart for the large investment flows into developing countries (e.g. large imports of manufacturing equipment or solar panels in Sub-Saharan Africa), as well as for the large human capital expenditure.[43] We will return later to the question of how these temporary but substantial trade imbalances could be financed (see section 8).

Once these assumptions on A-matrices and trade flows are specified, we can compute each country-level GDP trajectory and sectoral structure on the basis of its GNE trajectory and input-output structure.

3.6. Sectoral Productivity Trends and Labour Hours 2025-2100

The last step of our macroeconomic simulations consists of modelling the evolution of sectoral productivity growth and sectoral labour hours. The main stylized fact arising from the historic data is that productivity growth has generally been higher in material sectors than in immaterial sectors, both at the world level and in each country or region. In particular, productivity growth in the Manufacturing sector has always been substantially larger than average productivity growth, generally with a gap of around 0.5-1% or more per year. Productivity growth in the Food sector has also always been larger than average, usually with a somewhat smaller gap (around 0.5% per year). In contrast, productivity growth in Education/Health, and to a lesser extent in Leisure/Culture and Other Services, has always been below average, with a gap generally around 0.5-1% per year. These gaps may seem small, but as they accumulate over time, they actually have enormous consequences for the structure of

[42] The geography of sectoral comparative advantage is likely to be very different in 2100 to what it is today. E.g. the countries that will be net exporters of solar energy or mining products will obviously not be the same than the net exporters of fossil fuels in 2025, and the location and magnitude of such trade flows appears to be very difficult to predict at this stage. So for simplicity we assume away all sectoral asymmetries in 2100 and focus our attention on within-sector trade. These benchmark assumptions could be relaxed and refined in the future.

[43] The large human capital expenditure in poor countries can be obtained both by mobiliizing the local labour force (in which case this will contribute to trade deficit in other sectors) and by importing more education/health services (see below).

labour hours that are required to produce given volume of goods and services in the various sectors.

For the future – both over the 2025-2100 period and for the post-2100 steady-state, which we further analyze below – we assume that sectoral productivity trends will broadly follow the same pattern as in the past, in particular with a significant productivity growth differential between Manufacturing/Food and Education/Health (see Table 13). Given the projected sectoral structure of GNE and GDP over the 2025-2100 period, this implies a major shift of labour hours away from material sectors towards immaterial sectors. According to our projections, the share of Education/Health in total economic labour hours rises from 11% to 43% between 2025 and 2100 at the global level (see Figure 31).[44] While this might seem substantial, it should be mentioned that this sector already represents 30-35% of total economic labour hours in countries like Sweden or Norway in 2025 (see Figure 32). Given the magnitude of future needs in Health/Education (especially in light of population aging and of rising access to higher education among the youngest generations), the projected rise from 30-35% to 43% in the world's most advanced countries might well turn out to be insufficient.

Generally speaking, we should stress that there are many uncertainties about the future sectoral productivity growth rates. Our simulations should be viewed as merely suggestive. They go qualitatively in the right direction, but the exact magnitudes are relatively uncertain and dependent on future technological progress. For instance, if the differential productivity growth rate between material and immaterial sectors is just a little larger than what we assume, the share of labour hours in education/health/public services might well converge toward 45-50% rather than 43%. We should also point out that the gap in productivity growth between Manufacturing/Food and Education/Health is well documented and is likely to persist in the future, but that the patterns are less clear in some of the other sectors. For instance, the Construction sector has been characterized by very low productivity growth over the 1970-2025 period (if not negative), not only at the global level (partly due to country composition effects), but also at the country level (e.g. in the USA, an issue which has attracted substantial attention).[45] Our assessment is that this is largely due to temporary factors,

[44] In our benchmark projections we assume that total labour hours and sectoral labour hours shares follow piecewise-linear country-level trends between 2025 and 2100, and sectoral productivities are assumed to adapt to these trajectories in order to deliver the required sectoral GDP trajectories. An alternative modelling assumption would be to simulate sectoral productivity trajectories at the country-level and deduct sectoral labour hours trajectories. The end points will be the same but the trajectories could be different. In practice this makes very little difference. See online replication package.
[45] See e.g. Goolsbee and Syverson (2023).

and that productivity growth in construction is likely to be close to average productivity growth in the future (see Table 13).[46] In case this does not happen, then the labour needs of the construction sector will be larger than expected. Similarly, we assume that productivity growth in the future will be faster in leisure/culture and other services than in education/health. First, because it has been this way in the past, and next because automation potential (e.g. in relation to artificial intelligence) is arguably higher in the former than in the latter (where interpersonal relations matter more). This is plausible, but other trajectories can also happen. We should stress that these assumptions matter for the future structure of labour hours, but have little or no impact for the projections on GHG emissions and climate change.

3.7. Post-2100 Steady State: The Continuation of Structural Transformation

For the sake of completeness, it is also useful to describe a potential post-2100 steady-state under the Sustainable Convergence scenario. By 2100, all countries have converged to the same level of per capita GDP and the same sectoral structure for production and expenditure, so the convergence process is over. For simplicity, we assume starting in 2100 a constant productivity growth rate equal to 0.8% and population growth rate equal to -0.1%,[47] as well as stable labour hours per capita.[48] The investment rate is assumed to have stabilized at 20% of GDP and the capital/GDP ratio at 600% (including 280% for housing and 320% for other capital).[49] All countries in the world are on a balanced growth path with per capita GDP growth rate equal to 0.8% per year and aggregate GDP growth rate equal to 0.7% per year.

However, this steady-state growth path is also characterized by the continuation of structural transformation. This is because we assume for the post-2100 period a persistent differential productivity growth rate between material and immaterial sectors,

[46] First, global population growth was much larger in 1970-2025 than what it is scheduled to be in 2025-2100, which heavily contributed to agglomeration effects and rising construction costs. Next, available evidence suggests that the construction sector has been able to appropriate some of the rent coming from booming housing prices over the 1970-2025 period, which has contributed in a significant manner to rising construction prices (for given volume of construction) and hence declining measured productivity (a situation which we do not project to happen again in the future). See Appendix Figures C1a-C2b and the discussion in Appendix A below.

[47] This is close to what we have for the 2080-2100 period.

[48] E.g. because of a stable share of working-age population in total population, stable employment rates and stable working hours per employed individual.

[49] More precisely, we assume that capital depreciation rates have converged to 1% per year for housing and 4% per year for other capital, so that it takes an annual investment rate of 4.8% of GDP in housing to stabilize housing capital stock at 280% of GDP (i.e. (1% + 0.7%)x280% = 4.8%) and an annual investment rate equal to 15.0% in other capital to stabilize other capital stock at 320% of GDP (i.e. (4% + 0.7%)x320% = 15.0%), hence a total steady state gross investment rate equal to 19.8%. See Appendix Table T2100 for complete computations and formulas.

similar to the gap observed in the past (see Table 13). As a consequence, we project that the share of labour hours in education/health/public services will keep rising in the future, from 43% in 2100 to 67% in 2200 (see Figure 33). In effect, this corresponds to the rise of the care economy. Education and health activities are assumed to be characterized by lower productivity growth than other economic activities. These projections are simply meant to illustrate that relatively small differentials in annual productivity growth rates can matter a lot in the long-run, and that the post-2100, post-convergence development path is likely to involve substantial structural transformation, in spite of a relatively modest aggregate productivity growth rate.

4. Other Scenarios: Productivist Convergence (PC) vs Persistent Inequality (PI)

We now move to the description of our alternative macroeconomic scenarios, before finally presenting the decarbonization scenarios in the next section. In addition to the Sustainable Convergence (SC) scenario, we consider two main alternative macroeconomic scenarios: the Persistent Inequality (PI) scenario and the Productivist Convergence (PC) scenario.

4.1. Main Characteristics of PI and PC Scenarios

In the Productivist Convergence scenario, we assume the same productivity trends as in the Sustainable Convergence scenario, but with no reduction in labour hours (see Figure 34). As a consequence, all countries converge to a higher per capita GDP level than under the SC scenario: 120k PPP euros 2025 rather than 60k euros (see Figure 35). In our view, the PC scenario corresponds to a trajectory with relatively high levels of international cooperation in order to facilitate cross-country economic convergence (including large investment flows in poor countries), but little political mobilization to reduce labour hours, total economic output, and material footprint.

In the Persistent Inequality scenario, we assume no reduction in labour hours (just like in the PC scenario), and little cooperation and mobilization to facilitate cross-country convergence, so that global inequality in per capita GDP persists at very high levels until 2100 (see Figure 36). Rich countries are richer than in PC scenario, but poor countries are a substantially poorer, especially in Sub-Saharan Africa, so that average per capita GDP is scheduled to be 101k PPP euros 2025, a level that is substantially higher than in the SC scenario (60k euros) but lower than in the PC scenario (120k euros). As there is no increased economic catch-up of the Global South, we assume that the world population in the PI trajectory follows the UN Medium scenario rather than the UN ABR scenario (see Figure 7 above). This means, world population is scheduled to reach 10.2 billion by 2100 in PI scenario, rather than 9.4 billion in the SC and PC scenarios. In effect, per capita GDP is about 15% smaller in PI scenario than in PC scenario, but total population is 8% larger, so that aggregate world GDP is only 8% smaller.[50]

Note that the growth rate of per capita GDP is equal to 1.7% per year at the global level over the 2025-2100 period according to the SC scenario, vs 2.7% according to the PC scenario and 2.4% per year according to PI scenario (see Table 14).

Finally, both in our baseline PI and PC scenarios, we assume a stable share of material sectors in total expenditure at 53% between 2025 and 2100 at the world level, i.e. approximately the same level observed between 1970 and 2025 (see Figure 37). This stands in contrast to the SC scenario, according to which the share of material sectors is projected to decline by 30% between 2025 and 2100 (see Figure 18 above).[51]

4.2. Comparison of Economic Scenarios to SSP

Central for the analysis of future trajectories in the IPCC Reports are the five Shared Socioeconomic Pathways (SSPs), which are scenario-based socio-economic pathways that the world could take over the coming century that are intended to cover a broad range of possibilities. The five SSP scenarios are “Sustainability” (SSP1), “Middle of the road” (SSP2), “Regional rivalry” (SSP3), “Inequality” (SSP4), “Fossil-fueled development” (SSP5). Given the important role the SSP scenarios play in the climate modelling literature, we briefly compare them to our macroeconomic and population scenarios.

Under our SC scenario, the total world GDP would grow by 1.9% per-year. This is quite close to the 2.0% per-year growth under the SSP1 scenario. A key difference is that Sub-Saharan Africa’s total GDP would grow slightly faster under the SC scenario (5.0%) compared to SSP1 (4.2%), while East Asia, Europe, and North America and Oceania would grow significantly slower (0.2%-0.4% vs. 1.1%-1.9%).

[50] See section 6 and Figures 43a-43b.
[51] In subsequent analyses of the emission drivers, we discuss several additional scenarios including PI and PC scenarios with faster sectoral transformation.

Similarly, the growth rates of world GDP under the PI and PC scenarios (2.4%-2.6%) are quite close to the growth rates under the SSP5 scenario. Other projections such as the World Energy Outlook make similar assumptions.[52]

Focusing next on population, global population grows to 9.4 billion in the SC and PC scenarios and a little over 10 billion in the PI scenario. In contrast, in the SSP1 and SSP5 scenarios, global population peaks at a little over 9 billion in 2060 and then declines to 8 billion by 2100, i.e. at a level slightly lower than today's global population. On the other hand, the SSP3 and SSP4 scenarios project much higher population than other SSP scenarios (13-14 billion).

Combining total GDP and population projections, we can compare per-capita GDP across the various scenarios. We find that per-capita world GDP would grow by 1.7% per-year under the SC scenario compared with 2.1% under SSP1 and 1.7% under SSP2. On the other hand, per-capita GDP would grow at 2.4% and 2.6% under the PC and PI scenarios, even slightly smaller than the 2.7% growth rate in SSP5.

The key difference of our Sustainable Convergence scenario to the SSP1 sustainability scenario are full convergence across all countries and sufficiency in rich countries. All countries reach the same per-capita GDP (60k PPP euros 2025) in the SC scenario and this is driven both by rapid convergence by the poorer countries and sufficiency in rich countries. In contrast, there is still considerable inequality under SSP scenarios, including in SSP1. Namely, per-capita incomes in Sub-Saharan Africa are only about one-third of the levels in richest countries by 2100 (see Table 15).[53]

4.3. SC, PI and PC Scenarios as Alternative Plausible Views of the Future

We will later return to the set of institutional and distributional transformations that are necessary to implement the Sustainable Convergence scenario. For now, we stress that all three scenarios correspond to alternative plausible views of the future, with lots of intermediate variants within each scenario and between them. As we have shown the projected growth rates are in a similar ballpark as the SSP estimates and we believe that all three scenarios – and their variants – could potentially happen in coming

[52] See e.g. International Energy Agency (2025), Table 2.2, p.107, according to which the world GDP growth rate is projected to be 2.6% per year over the 2025-2050 period (including 4.0% in Subsaharan Africa and 4.9% in India). Note however that such scenarios typically cover shorter periods (e.g. 2025-2050 in WEO projections rather than 2025-2100 in our projections) and are not always explicit about population projections and the possibility and timing of complete convergence in per capita GDP.
[53] See Appendix Table X3a for the complete comparison between our scenarios and the SSP scenarios, including population and total GDP.

decades, depending on the balance of political and ideological power. The PI scenario is arguably closest to a pure "business-as-usual" (BAU) scenario, in the sense that it requires no major policy action or change in course. In particular, it requires no international coordination in order to foster cross-country convergence, no reduction in labour hours to limit consumption, and no compression in the relative size of material sectors. In that sense, it can be viewed as the most likely scenario, especially in light of the enormous governance and institutional challenges associated to global cooperation.

However, there are also powerful political forces pushing in favour of the PC scenario and the objective of cross-country convergence, not only in the Global South but also in the Global North (e.g. due to internationalist values and/or the fear of migration pressures). Note that the PC scenario has a lot in common with the PI scenario: both share a productivist and market-driven orientation and make limited effort to address the global warming challenge. The main difference is that the PI scenario corresponds to a more nationalist and less cooperative trajectory (and a potentially more authoritarian trajectory, both in the North and in the South, in particular in order to confront migration pressures), while the PC scenario assumes that liberal internationalist principles of market-driven global cooperation will prevail. The problem of this scenario, as we shall see, is that it is likely to lead to catastrophic global warming and a severe decline in planetary habitability, in a similar manner as the PI scenario.

In practice, the threats to planetary habitability and the social demand for free time and sustainable well-being can contribute to make the SC scenario, which can be viewed as closer to social-democratic or democratic socialist principles and values, the most desirable scenario for many, and arguably the only way to reconcile socioeconomic prosperity and planetary habitability. It is also the most challenging, in the sense that it requires the largest change in institutional structures and public policies. We hope that our analysis of climate change trajectories and comprehensive well-being under the three scenarios can contribute to clarifying the discussion and the issues at stake and can help readers make their own opinion about these complex issues and choices.

5. From Macroeconomics to Emissions: The Transition of The Energy System

In order to assess the impact of the different scenarios for the evolution of expenditure and growth on GHG emissions, we combine them with scenarios on the evolution of the energy sector and industrial processes. For energy-related combustion emissions, we track the energy demand of each production sector and households through the input-output framework. To that end, in our modelling framework we disaggregate the Energy sector in up to 14 subcategories covering different types of primary energy sources (coal, oil gas, …) as well as electricity generation types (coal power, hydro power, solar power…). We refer to Table 2 (section 2.1) for an overview of the additional sectoral disaggregation in the IO framework. This approach allows us to apply emission intensities of different primary inputs rather than aggregate sectoral emission intensities per unit of GDP. More precisely, we use GTAP 2017 data to obtain the kilograms of CO2, methane, nitrous oxide, and F-gases emitted through the combustion of one euro's worth of coal, gas or oil products (which, as discussed in section 2, is equivalent to fixing physical emission intensities in our constant price framework).[54]

We first provide a general description of our three different energy scenarios: a Slow Decarbonization (SD) scenario, an Intermediate Decarbonization (ID) scenario, and a Fast Decarbonization (FD) scenario (section 5.1). For each individual aspect and scenario, we then discuss our assumptions regarding the evolution of the composition of sectoral energy demand (section 5.2), the patterns of electrification (section 5.3) and the improvements in energy efficiency (section 5.4). Finally, we explain how industrial process emissions are projected by linking them directly to sectoral GDP in our Manufacturing and Water/Waste sectors (section 5.5).

5.1. Three Scenarios for Decarbonization: Slow, Intermediate and Fast

We model the evolution of the energy system over 2026-2100 across three key dimensions: the composition of final energy demand for the total economy, by production sectors and by households; the generation mix of electricity, and improvements in energy efficiency (reductions in total energy demand per unit of sectoral output). We specify all assumptions in physical terms and subsequently translate them into monetary terms via relative prices, as described in section 2.

Electrification, sectoral fuel mix, and improvements in energy efficiency jointly determine the evolution of energy-related emissions in our framework – the first two affect the carbon intensity of energy use (emissions per unit of energy), while efficiency gains reduce absolute energy demand per unit of sectoral output. The interdependence among these parameters should be emphasized. E.g. higher electrification does not necessarily reduce emissions if additional electricity is

[54] Future versions of this research will integrate the latest GTAP updates (in particular regarding years 2019 and 2023) in our framework.

generated from carbon-intensive sources. Conversely, decarbonizing the electricity generation mix has limited impact in sectors where fossil fuels dominate non-electric energy demand. And even under ambitious electrification scenarios, certain industrial processes (such as high-temperature heat in steel and cement production) cannot feasibly be electrified, but have to be decarbonized through the substitution of fossil fuels by low-carbon alternatives such as green hydrogen or biofuels. Similarly, improvements in energy efficiency reduce total energy demand per unit of output but leave carbon intensity unchanged unless accompanied by a parallel shift in the fuel mix toward lower-carbon sources.

By decomposing emissions into their determinants rather than imposing a single exogenous emission intensity on aggregate output, our approach allows us to model these underlying structural drivers of energy-related emissions explicitly. As discussed in section 2, this is a key methodological feature of our framework insofar as it yields a transparent set of assumptions that can be modified independently to construct alternative scenarios or to conduct sensitivity analyses.

We propose three energy scenarios, which will be combined with the three macroeconomic projections described in sections 3 and 4: a Slow Decarbonization (SD) energy scenario, an Intermediate Decarbonization (ID) scenario, and a Fast Decarbonization (FD) scenario. The SD scenario broadly corresponds to the policies that are currently followed by the various countries at play. The ID is a more proactive scenario which roughly corresponds to country official commitments and pledges, including policies that are not yet implemented. The FD scenario is the most ambitious scenario and has been designed in order to preserve planetary habitability.

These energy scenarios are close in spirit to the three scenarios developed by the International Energy Agency in their 2025 World Energy Outlook (IEA 2025), namely the CPS, STEPS and NZE scenarios. The IEA’s Current Policies Scenario (CPS) takes into account only those climate and energy policies already enacted and implemented as of the data cutoff, with no assumption of future legislative action or additional policy commitments. It therefore represents a lower bound of the energy transition, in which fossil fuel dominance persists. The Stated Policies Scenario (STEPS) goes further by incorporating not only enacted legislation but also announced policy intentions and targets such as national renewable energy commitments, even where these have not yet been formally legislated. The Net Zero Emissions Scenario (NZE) specifies the conditions under which net zero CO_2 emissions are reached globally by 2050. It assumes unprecedented deployment of clean energy technologies and deep electrification across all sectors of the economy.

We map these three IEA scenarios onto our energy sectors as follows: the SD scenario draws on the Current Policies Scenario; the ID scenario draws on the Stated Policies Scenario; and the FD scenario draws on the Net Zero Emissions scenario. As was already noted, one significant difference with IEA scenarios is that we do not assume large-scale carbon capture and carbon removal to achieve net zero. We instead rely land-use changes. In our core projections, we will combine the PI and PC macroeconomic projections with either the SD or ID energy scenarios, and the SC macroeconomic scenario with the FD energy scenario. We will also combine the FD energy scenario with PI and PC macroeconomic assumptions in order to approximate what standard "green growth" projections might imply in terms of planetary habitability.

Some limitations of our energy scenarios deserve explicit acknowledgement. First, the IEA scenarios are defined over three aggregate *end-use sectors* (Industry, Buildings, and Transport), whereas our IO framework is organized around *eight production* sectors. A hospital's own vehicle fleet, for example, would be recorded under Transport in the IEA framework but under Education/Health in our IO framework. Translating between these two accounting frameworks requires assumptions that we describe transparently so that future work can readily modify them. Second, IEA projections extend only to 2050, while our simulation horizon runs to 2100, necessitating extrapolation beyond the range of established forecasts. Third, our framework applies energy transition assumptions exogenously, abstracting from the price feedbacks that are central to the IEA's scenario logic: we do not model how changes in relative energy prices (driven for example by carbon pricing or technology cost reduction) might accelerate or retard electrification and fossil fuel switching across sectors. While these are inherent challenges of integrating energy and macroeconomic scenario frameworks over long time horizons, we consider the explicit documentation of our assumptions as a contribution itself, insofar as it renders our scenarios transparent, reproducible, and open to systematic sensitivity analysis by future research.

5.2. Composition of Total and Sectoral Energy Demand

5.2.1. Electrification Shares

In Figure 38, we describe the evolution of the energy mix of the total world economy over the 2025-2100 period under the three scenarios: Slow, Intermediate and Fast

Decarbonization. As one can see, the key characteristic of the FD scenario as compared to both the SD and ID scenarios is the relatively fast phase-out of fossil fuels. Fossil fuels represent less than 20% of total energy demand in 2050 (and 0% by 2100) in the FD scenario, as compared to 55-60% in 2050 (and 40-50% in 2100) according to the SD and ID scenarios. Figures 39a-39c describe the corresponding evolution of the electrification shares by sectors in the three scenarios.

We largely base our projections of sectoral electrification shares on the corresponding IEA scenarios.[55] As noted above, the IEA makes projections for three broad *end-use sectors,* Industry, Transport, and Buildings, which do not align exactly with our eight disaggregated production sectors and households. We decided to apply the following concordance: Food, Construction, and Manufacturing are mapped into IEA's Industry sector; Housing Services, Education/Health, Leisure/Culture, and Other Services to Buildings; Transport to Transport; and Households to a weighted average of Buildings and Transport, reflecting the typical composition of household final consumption based on the typical breakdown of household energy use between residential buildings and personal vehicle use.

For each of our sectors, we project electrification shares by applying the absolute annual change (in percentage points) observed in the corresponding IEA sector. We prefer this additive approach over a multiplicative approach (in which sectoral shares would be scaled by IEA growth multipliers) for two reasons. First, baseline electrification shares differ between GTAP and IEA sector definitions, particularly in transport (2% in IEA vs. 6% in GTAP). This discrepancy arises because the GTAP Transport sector includes electrification of transport services such as rail operators. When starting from different baselines, applying growth multipliers can produce highly distorted projections. Second, the additive approach can be understood as reflecting more closely the nature of the underlying energy transformation. An increase of, for example, six percentage points in transport electrification at the end-use level implies a broadly similar increase in transport service provision, even if absolute levels differ. To prevent electrification shares from reaching economically implausible levels, we impose sector-specific ceilings, reflecting the fact that for certain processes such high-temperature industrial heat in steel and cement production electrification remains prohibitively costly relative to substitution by low-carbon fuels. This yields electrification

[55] Note that our "electricity" sector includes both electricity and district heat, in accordance with the GTAP data we use. Reassuringly, the total economy-wide share of electricity and district heat in final energy demand according to the IEA WEO is 25% in 2025, which aligns almost perfectly with our IO-based estimates in 2025 (24%).

shares in 2050 ranging from 12% (Transport, SD) to 87% (Leisure/Culture, FD), and in 2100 from 21% (Transport, SD) to 95% (Leisure/Culture, FD) (see Figures 39a-39c).

Of course, this approach is far from perfect: Our assignment of the IEA's Buildings electrification growth rate to sectors like Education/Health assumes that these sectors' energy demand is dominated by building-related consumption (space heating, cooling, lighting, appliances), even though these sectors also use means of transportation (ambulances, school busses), which is captured separately in IEA's Transport sector. Similarly, we ignore the fact that sectors like Manufacturing use building-related energy for office and factory spaces, which would suggest a partial link to the IEA's Buildings sector in addition to its primary link to the Industry sector.

Despite these limitations, we believe this approach represents the best available mapping given data constraints. Our baseline electrification shares in 2025 show reasonable alignment between out sectors and their corresponding IEA categories: the weighted average of our three industry-mapped sectors (Food, Construction, Manufacturing) is 23%, which is relatively close to IEA's Industry sector (28%); similarly for buildings-mapped sectors (52% vs 44% in IEA), and transport (6% vs 2% in IEA). At the aggregate level, our projected total economy electrification shares align closely with IEA projections throughout the projection period, with deviations of at most 1 percentage point.

5.2.2. Non-electric energy demand

For the composition of non-electric energy sources (i.e. the mix of coal, natural gas, oil, and low-carbon alternatives such as clean biofuels, hydrogen, and synthetic fuels), we follow a similar approach: We obtain annual changes between 2024-2035 and 2035-2050 from the IEA, and then extrapolate them to 2100 using the additive approach. As before, we validate the sectoral mapping by checking that aggregate economy shares of fossil and low-carbon fuels align closely with IEA projections. In our SD energy scenario, the share of low-carbon primary fuels in total energy demand remains relatively stable between 2024 and 2035, reflecting limited policy intervention and slow technology deployment. It then rises gradually in sectors such as Transport (Manufacturing) to 8% (5%) by 2050 and 15% (7%) by 2100. This implies that fossil fuels continue to dominate non-electric energy use throughout the century under current policies. By contrast, the FD scenario assumes a much faster transition: the low-carbon fuel share in Transport (Manufacturing) rises to 14% (8%) in 2035, 28%

(21%) by 2050, and reaches 30% (40%) by 2100, implying complete phase-out of fossil fuels in primary energy by the end of the century (see Figures 40a-40h).

5.3. Generation of Electricity

We now present our assumptions about the future generation of electricity. For the 2025-2050 period, we adopt the generation mix from the corresponding IEA scenarios directly (see Figure 41). Our three energy scenarios share a common 2025 baseline and diverge substantially after, with low-carbon sources reaching 68%, 79%, and 99% of total generation by 2050 under the SD, ID, and FD scenarios respectively. One modification which we make to the IEA scenarios concerns nuclear power in the FD scenario: given that nuclear energy raises unresolved concerns regarding safety, waste disposal, and proliferation risk, we assume that its share in electricity generation reduces by about one third until 2050, redistributing the difference to solar and wind proportionately. For the 2050-2100 period, we extrapolate by adding the absolute annual change in percentage points of each electricity source's share in 2050. This yields low-carbon shares of 90%, 100%, and 100% by 2100 under the SD, ID, and FD scenarios respectively.

One technical remark concerns the treatment of district heat, so heat generated centrally in combined heat and power plants or dedicated heating facilities and distributed to buildings via insulated pipe networks. The electricity category in our GTAP data includes district heat alongside electricity, whereas the IEA projections cover electricity generation only. Our 2025 IO baseline and the IEA's 2024 electricity generation mix are nonetheless closely aligned: both show coal at around 35%, gas at 19-22%, hydro at 15%, and solar and wind combined at 15-17%, with the main discrepancy arising from GTAP's "Other baseload" category, which captures other carbon-intensive generation and which has no direct counterpart in the IEA data. We therefore apply the IEA projections directly to our combined electricity and heat aggregate, justified by the fact that electricity constitutes the dominant share of the combined category (21% of global final energy consumption in 2023, compared to 3.6% for district heat).

5.2.3. Energy Efficiency Improvements

Reductions in sectoral energy demand per unit of output in our projections arise from two distinct sources. First, electricity delivers useful energy services more efficiently than direct fossil fuel combustion. At the point of use, electricity operates at approximately 100% conversion efficiency (after accounting for transmission and distribution losses), while fossil fuels experience substantial conversion losses depending on the application. We apply sector-specific end-use efficiency gains based on the pre-transition versus post-transition analysis in Eyre (2021), Ritchie (2023), which examines the energy requirements to deliver identical services across the three broad sectors Industry, Transport, and Buildings. We map these efficiency factors to our eight production sectors and GNE using the same correspondence applied for electrification share projections from the WEO (see section 5.2.1).

Second, beyond electrification, energy efficiency improves through technological progress and behavioural changes such as better insultation in buildings or process heat recovery in industry. To capture these residual efficiency gains, we use economy-wide projections on energy intensity improvements from the IEA's three scenarios, subtract the component attributable to electrification-driven efficiency gains (calculated as described above), and apply the resulting residual efficiency improvements uniformly across all production sectors. This approach ensures that our total energy efficiency pathway matches IEA projections.

Note that these energy efficiency improvements only capture end-use inefficiencies, so losses in the conversion from final to useful energy. Conversion losses in the transformation of primary energy into final energy (e.g., coal into electricity) are inherently captured in the input-output matrix coefficients. For example, the coal to coal-powered electricity A-matrix coefficient is 0.42, which implies that producing one euro of coal-powered electricity requires to spend 42 cents on coal as an intermediate input. At the same time, renewable energy sources (solar, wind, hydro) have zero or near-zero fuel input coefficients since they require no combustion. The IO table thus captures not only which inputs are needed to produce electricity, but also how much of each input is required given the technological realities of energy conversion. These technological coefficients remain fixed throughout our projections; what changes is the composition of electricity generation, which alters the aggregate primary energy requirements of the energy sector without changing the underlying production structure for each generation technology.

5.3. Industry-Related Emissions

As discussed in section 2, we project the emission intensity of output of Manufacturing and the Water/Waste sectors for industry-related emissions. We assume emission intensities decline linearly from 2025 baseline levels, with cumulative abatement rates of 20%, 40%, and 90% in our SD, ID, and FD scenarios respectively (Figures 42a-42b). The 20% reduction in the SD scenario represents incremental improvements through efficiency gains and modest material substitution. The 90% reduction in the FD scenario assumes aggressive deployment of carbon capture and storage at cement and chemical plants, large-scale adoption of alternative chemistries, and substantial demand reduction through material efficiency and recycling.

This treatment is considerably more stylized than our energy system modelling: we do not explicitly model individual abatement technologies. However, our assumptions are broadly consistent with existing decarbonization pathways: The IEA Net Zero Emissions scenario projects net industrial process emissions falling by 30% by 2035 and by 95% by 2050 relative to 2024 levels, reaching approximately 0.4 Gt CO2e by mid-century. Our Fast Decarbonization scenario, which projects a 90% reduction by 2100, represents a similarly ambitious trajectory extended over a longer timeframe.

We acknowledge that achieving the described improvements in both the energy sector and in industry would require substantial investments in new technologies and infrastructure. While we do not model the related capital costs explicitly within our emission intensity projections, we do account for the macroeconomic implications of the energy transition through higher investment rates during the transition period, as detailed in sections 3 and 7. The financing mechanisms and distributional implications of these investments – including the role of public finance and redistribution within and between countries – are analysed in our companion paper (Bothe et al., 2026).

6. Planetary Habitability: Sustainable Convergence vs Other Scenarios

We can now compare the economic and environmental implications of our various scenarios – Sustainable Convergence (SC), Persistent Inequality (PI), and Productivist Convergence (PC). We start with the GDP and material expenditure trajectories. We then analyse the resulting projections for total GHG emissions (CO2 and non-CO2) and temperature rise across the three scenarios.

6.1. Sustainable Convergence: Large Material Degrowth Relative to Alternatives

According to our projections, aggregate world GDP is scheduled to rise from about 139T (trillion euros 2025 PPP) in 2025 to approximately 565T in 2100 in the Sustainable Convergence scenario. In comparison, aggregate world GDP is projected to rise to 1023T in the Persistent Inequality scenario and 1130T in the Productivist

Convergence scenario (see Figure 43a). In effect, the real growth rate of world GDP, which was equal to 3.2% per year on average between 1970 and 2025, is projected to slow down to 1.9% per year between 2025 and 2100 in the Sustainable Convergence scenario, vs. 2.7% and 2.8% per year in the other two scenarios. While this can seem like a small gap in terms of annual growth rate (with a differential around one percentage point per year), the cumulated effect over the 2025-2100 period is substantial. By 2100, the world economy – i.e. the real quantity of goods and services produced in the world – is about twice as small in the Sustainable Convergence scenario than in the two alternative scenarios.

Note that the gap between the SC trajectory and the PI and PC trajectories rises over time during the 2025-2100 period and is already quite large by 2050. In the SC scenario, aggregate world GDP is projected to be equal to 73% of the PI level in 2050 and 55% in 2100. The gap is even larger if we focus on material sectors (Food, Construction/Housing, Manufacturing, Energy, Transport), where total world expenditure (final consumption and investment) in the SC scenario is projected to be equal to 69% of PI level in 2050 and 37% in 2100 (see Figure 43b).

In other words, by 2100, the real quantity of total world expenditure in these material sectors is almost three times smaller in the SC scenario than in the other two scenarios. In that sense, the SC scenario does represent a significant attempt to apply the principles of material degrowth. As we shall see next, however, such compression of the material footprint brought by the sharp reduction of labour hours, changing food habits and the fall in the expenditure share of material sectors alone is insufficient to stay within 2°C. In addition, the accelerated transformation of global energy systems and land use structures is essential.

6.2. Projected GHG Emissions and Temperature Rise

We now present aggregate emission pathways and related temperature changes under our different scenarios (Figure 44). Let us start with our growth-focused macroeconomic scenarios PI and PC, both of which constitute continued growth in material and immaterial sectors without labour hours reduction or consumption changes. When coupled with Slow Decarbonization – maintaining current policy trajectories, so following only incremental improvements in energy efficiency and renewable deployment – these scenarios result in cumulative emissions of 7250-7500 GtCO2e over the 2025-2100 period, causing an expected temperature rise of 4.8°C to 4.9°C above pre-industrial levels by 2100. Aggregate emissions under the two scenarios are similar because, despite PI involving sustained inequality across countries while PC achieves full convergence to 120k Euros per capita, aggregate world GDP and especially the average growth rates in the first decades are very similar under the two scenarios. This highlights once again that global inequality per se is not a primary determinant of emissions: what matters is the total scale of economic activity, its sectoral composition, as well as decarbonization efforts, not how the activity is distributed across countries. Compared to an equally large world economy with continued between-country inequality, convergence has no additional cost in terms of emissions.

Adding sufficiency (reduction of work hours by 50% by 2100, the shift from material to immaterial consumption, and the change in food patterns) reduces aggregate carbon emissions between 2025 and 2100 to 3635 Gt CO2e, which reduces the projected temperature rise to 3.3°C by 2100 (1.6°C degree lower than the PC scenario). While this on the one hand shows the emission reduction potential of sufficiency, it also underlines that without an accelerated decarbonization of the energy system beyond current policies, we far exceed the 2°C temperature target.

When we add the fast decarbonization of the energy system (broadly in line with the IEA's Net-Zero Emissions scenario) on top of the sufficiency in growth and consumption patterns, total projected GHG emissions between 2025 and 2100 fall to 1075 Gt CO2e, which results in a projected temperature by 2100 of 1.8°C, thus, remaining below the 2°C threshold.[56] Importantly, the only pathways of convergence that stay within 2°C rely both on sufficiency, i.e. limits to growth and consumption changes, and on a fast decarbonization (see more below). This underscores the central finding of our paper: planetary habitability and global prosperity are compatible only through a comprehensive transformation encompassing how we consume, work, and produce.

We should highlight that in the PI and PC scenarios, net emissions remain positive throughout until the end of the 21st century, meaning atmospheric CO2e concentrations

[56] Note that our Sustainable Convergence with Fast Decarbonization projections yield 13.8 Gt CO2e in 2050, which may appear confusing given that our decarbonization assumptions closely follow the IEA's *Net Zero Emissions* Scenario. There are two main explanations. First, the IEA models only CO2, whereas our scenario accounts for all greenhouse gases. Of our 13.8 Gt, 10.2 Gt are non-CO2 emissions, including approximately 5 Gt from agriculture. Second, our remaining 3.6 Gt of net CO2 reflect weaker assumptions on carbon capture: the IEA relies on approximately 6 Gt of carbon capture and 2 Gt of carbon removal in 2050 in order to reach net zero CO2, whereas we assume only much slower deployment of carbon capture at industrial sites. Note that these emissions differences cannot be explained by diverging macroeconomic assumptions: GDP and population projections are similar at the world level across both IEA and our scenario.

would continue to rise beyond 2100. This implies that the temperature increases shown (4.8-4.9°C) represent 2100 values, not temperature peaks. Temperatures would continue rising after 2100 as long as net emissions remain positive. Only the SC scenario with fast decarbonization achieves net zero emissions by 2100 thanks to a fully energy decarbonization, limits to industrial processes and substantial negative emissions from reforestation thanks to changed food habits, allowing temperatures to stabilize close to the 2°C level shown.

A striking way to illustrate the radical decrease in emissions necessary to stay within the 2°C target is to place them in the long-run historical context. Figure 45 illustrates the evolution of global aggregate CO2e emissions since 1850 and post-2025 for our main scenario of Sustainable Convergence to 60k euros, consumption pattern changes, and fast decarbonization. Emissions rose steadily throughout the industrial era, accelerating dramatically after 1950 to reach a peak of approximately 56 Gt CO2e around 2025. In our most optimistic scenario, emissions must then decline precipitously, falling to below net 0 in 2100, with energy sector emission approaching zero, and remaining industrial process emissions offset even more than completely by negative emissions from land-use changes. In other words, our trajectory to global convergence within planetary habitability requires reversing in just 75 years what took 175 years to build up. In order to make this happen, two key ingredients need to be combined: a rapid phase-out of fossil fuels, and a strict deforestation ban enforced in 2030, followed by gradual reforestation bringing global forest cover back to 1900 level by 2100.

6.3. Decomposition of Emissions Drivers: Socioeconomic Sufficiency and Energy Transition Are Complementary

Let us have a closer look at the drivers of emissions reductions across our PC-SD and SC-FD scenarios, in order to better understand the relative roles of sufficiency and the energy transition, as well as their respective sub-components. To determine the marginal contribution of each of these factors, we compute their Shapley values by averaging each factors contribution to emissions across all possible orderings.

The results are presented in Figure 46. Overall, sufficiency is responsible for about 44% of the emission reduction: 26% can be attributed to the reduction in global annual labour hours, while the shift in consumption patterns from material to immaterial sectors accounts for 8% of the decrease in emissions. Finally, changing food patterns explain a further 10% reduction through their impact on both livestock farming and land use – as reduced agricultural land use enables reforestation and the creation of natural carbon sinks.

The remaining 56% of emission reductions are attributable to the energy transition. We find that about 24% of energy-related emissions reductions stem from electrification broadly defined: 10% from the increasing share of electricity in final energy demand, and 14% from decarbonizing electricity generation. About 16% of the reduction is attributable to changes in the composition of primary fuels, particularly the relative reduction of coal and increase of low-carbon fuels. 6% of emissions are saved from increased energy efficiency from both electrification as well as behavioural and technological advancements. Lastly, 10% result from our assumptions on decreasing emission intensities of industrial processes and waste management.

These decompositions demonstrate that no single lever dominates. Both sufficiency (44%) and the energy transition (56%) contribute substantially to total emissions reductions – achieving compatibility between global prosperity and planetary boundaries hence requires simultaneous transformation across the economic structure and energy systems.

6.4. Can PI and PC Scenarios Be Combined with Fast Decarbonization?

Given the powerful impact of technological changes on total emissions, why not simply grow according to our PI or PC scenarios but make sure that we follow the fast decarbonization energy transition path?

There are several problems with this view. Generally speaking, it seems very unlikely that PI and PC scenarios can come with Fast Decarbonization. Even a shift from Slow Decarbonization (which corresponds approximately to current policies) to Intermediate Decarbonization (which is closer to official country commitments) would require enormous policy actions. The resulting temperature rise would be reduced from about 4.8°C-4.9°C to 4.1°C-4.2°C, which would still be very large (see Figure 47).

Let us now assume, for the sake of reasoning, that the PI and PC scenarios can indeed be combined with Fast Decarbonization. Figure 48 shows that such scenarios yield cumulative emissions of 2674 Gt CO2e and 2706 Gt CO2e over our projection period (compared to 7300-7500 Gt CO2e under slow decarbonization), translating into a temperature rise of 2.6°C by 2100. In addition, emissions continue to grow thereafter, and temperature rise could reach around 2.9°C-3.0°C by 2200, because of remaining industrial emissions and emissions from livestock farming that are not fully offset by forests. From a purely technical perspective, these scenarios demonstrate that accelerated transformation of energy systems and industrial processes can reduce emissions substantially by the end of the century even without the sufficiency elements that characterize our SC scenario but cannot reach net zero emissions.

In any case, we remain sceptical of such "green growth" pathways for two main reasons. First, there are other planetary boundaries beyond climate change (biodiversity loss, nitrogen and phosphorus cycles, freshwater depletion, ocean acidification), which we do not measure here but which cannot be avoided through decarbonization alone. A pathway that maintains material consumption growth at current rates while decarbonizing production processes may still transgress these other boundaries through continued pressure on ecosystems, resource extraction, and pollution. Decarbonization is necessary but not sufficient for comprehensive planetary habitability.

Second, we question whether such pathways are culturally feasible. If societies prioritize maintaining current growth and consumption trajectories above all else, the political will to accept the disruptions and costs required for fast decarbonization is unlikely to materialize. Fast Decarbonization requires rapid retirement of high-carbon assets, massive investment in renewable energy infrastructures,[57] substantial increases in energy costs during the transition, and industrial policies that constrain consumer choice – sacrifices that are difficult to sustain politically without a compelling vision of why they are worthwhile. The sufficiency narrative in our SC scenario aims to provide precisely such a vision. Rather than framing decarbonization as sacrifice in service of continued material accumulation, it reframes the transition as an opportunity to build a more equitable and sustainable way of life. As we will discuss in section 7, working fewer hours, reorienting consumption toward services, eating in a more sustainable (and healthy) manner, sharing prosperity globally, and living within a stable climate can plausibly increase human well-being compared to the trajectory of endless work and material growth.

Lastly, simultaneously pursuing rapid growth and fast decarbonization presents significant political challenges, as existing economic structures often resist ambitious climate policy. Societies organized around material consumption growth develop political economies (lobbying groups, cultural norms, media narratives) that resist

[57]See section 7 for a discussion of total financing needs associated to fast decarbonization and sustainable convergence.

disruption to those consumption patterns. As countries shift toward less and more immaterial consumption and reduce working hours, industries tied to material output shrink relative to those providing services, shifting the balance of political power. Policies constraining material consumption face less resistance in such a scenario because they align with, rather than contradict, the direction society is already moving. Overall, we believe that fast decarbonization and structural transformation are two mutually reinforcing and jointly necessary forces for building the cultural consensus and political coalitions required to sustain planetary habitability over the long term.

6.5. Global Convergence at 60k Euros or Less: Can Degrowth Do Better?

If our assumptions about decarbonization and consumption shifts prove too ambitious, does global income convergence remain an objective that can be realized within planetary boundaries? Figure 49 presents scenarios with convergence to 45k euros, 30k euros, and 15k euros per capita GDP rather than 60k euros, without the assumptions on shifts in consumption patterns that characterize our SC scenario, and combined with intermediate rather than fast decarbonization (so a “pledged policies” trajectory, rather than a “net zero” one). For reference, 45k euros per capita corresponds roughly to Spain’s or South Korea’s current living standard (2025), while 30k euros corresponds to Argentina’s or Bulgaria's. 15k euros sits at today’s global average GDP per capita, and is observed at the country level for example in Vietnam or Tunisia.

Under SC-45k-ID, cumulative emissions over our projection period reach 3,464 Gt, yielding 3.0°C of warming by 2100. Under SC-30k-ID, cumulative emissions are at 2845 Gt, yielding 2.7°C. Lastly, the SC-15k-ID results in 2138 Gt, implying 2.3°C. This compares to a temperature rise of 3.3°C in SC-60k-ID. These results demonstrate that if fast decarbonization and shifts in consumption patterns prove unattainable, even “degrowth” in today’s rich countries cannot limit warming to tolerable levels.

Let us now conduct the same exercise assuming fast decarbonization but still no shifts in consumption patterns – that is, a world in which the energy transition progresses rapidly but consumption patterns (including food habits and deforestation patterns) remain unchanged. What would lower convergence targets of 45k, 30k or 15k euros per capita imply in terms of emissions? Figure 50 illustrates that the SC-45k-FD scenario yields cumulative emissions of 1733 Gt CO_2e by 2100, implying a temperature rise of 2.1°C by the end of the century, while the SC-30k-FD scenario yields 1494 Gt CO_2e and a 2.0°C rise. Under the SC-15k-FD scenario without sectoral change, aggregate emissions are projected to reach 1198 Gt CO2e, with a corresponding rise in temperature of 1.9°C above pre-industrial levels by end-century. Note that in all those scenarios, net emissions in 2100 exceed zero, implying that temperature continue to rise in the following century.

These results reveal that even global convergence to 30k euros – which represents Argentina- or Bulgaria-level prosperity rather than Norway-level – exceeds the 2°C threshold in the long run if it does not come along with consumption shifts. The 15k euros scenario – convergence of all countries to today's global GDP per capita average – can produce the same temperature outcome as the 60k euros scenario with a consumption shift, but may even fare worse beyond 2100. Overall, our results clarify that global income convergence to current high-income country living standards is only possible when fast energy transition is complemented by sufficiency in consumption patterns and food habits.

Interestingly, our findings also illustrate the fact that “targeted sufficiency” – for instance a 60k target with a large consumption shift to immaterial sectors, change in food habits and implied deforestation – can be more effective than large uniform degrowth (such as a 15k target with no sectoral change) (see Figure 50). In other words, the sectoral composition and consumption patterns matter – and not only the level of GDP. We hope that these simulations spanning energy transition, sectoral change, sufficiency, and degrowth trajectories can contribute to open new ground for both academic and public discussion on these fundamental issues.

7. Beyond GDP: Assessing the Impact on Comprehensive Well-Being Indicators

We now turn to the consequences of the various scenarios for comprehensive human well-being. At the outset, it is important to recognize that a growing body of evidence suggests that several dimensions of climate damages cannot be fully valued in monetary terms. The loss of biodiversity, for instance, far exceeds the narrow economic contribution that ecosystems provide to measured output. Another example are the substantial risks of climate change on health and mortality, which are difficult to quantify monetarily and which raise deeper questions about whether such valuation is appropriate at all (Stern 2007, Romanello et al. 2024). Moreover, the structure of climate risks is characterized by non-linearities and potential tipping points—such as permafrost thawing with methane release or large-scale disruptions of oceanic circulation—which raise fundamental challenges for attempts to express climate damages as smooth, monetized loss functions (Lenton et al., 2008; Weitzman, 2009).[58]

These considerations imply that not all climate damages are straightforwardly compensable through higher material consumption. Any welfare framework that aggregates environmental degradation and consumption into a single scalar index therefore embeds substantive normative assumptions regarding commensurability and substitutability.

Against this background, it remains informative to examine how the different scenarios compare under broad measures of economic well-being. If one focuses exclusively on per capita GDP, then by construction the Sustainable Convergence (SC) scenario yields lower global average income than the other two scenarios. According to our projections, world per capita GDP reaches approximately 60k euros (PPP, 2025 euros) by 2100 in the SC scenario, compared to 101k euros under Persistent Inequality (PI) and 120k euros under Productivist Convergence (PC). Under a purely income-based metric, average material living standards are therefore lower in SC than in the alternative pathways.

However, the value of planetary habitability, as discussed above, as well as the value of extra free time (leisure), which is not captured by GDP but enters standard welfare analysis, deserve explicit consideration. We begin with the valuation of leisure and turn to the more complex issue of incorporating planetary habitability into the welfare assessment, which raises deeper questions about the extent to which environmental degradation can be expressed in monetary terms.

7.1. Adding the Value of Free Time (Leisure)

Annual labour hours per employed individual are assumed to be 1000 hours per year (i.e. 25 hours per week during 40 weeks, with 12 weeks of paid vacations) in all countries in 2100 in the SC scenario, as opposed to 2000 hours per year (i.e. 40 hours per week during 50 weeks, with 2 weeks of paid vacations) under the PI and PC scenarios. For simplicity, we assume that additional leisure hours bring on average the same marginal welfare as worked hours (via extra income and consumption). In other words, by adding the value of leisure to per capita GDP, we find that the true average

[58] As Weitzman (2007) argued, climate policy may be better understood not as a problem of consumption smoothing, but as one of insurance against low-probability, high-impact catastrophic outcomes.

well-being – which we refer to as augmented GDP – associated the sustainable convergence scenario is equal to 120k rather than 60k (see Figure 51a).

Generally speaking, this assumption is likely to underestimate the value of extra leisure. Historically, we observe a very large reduction in working hours, and our projections for the future in SC scenario are in line with this evolution (see Figure 5 above). The fact that this historical evolution did happen – and was not reversed in any country – strongly suggests that the marginal welfare value of leisure was actually larger than the welfare value of worked hours. In addition, one might expect collective norms and preferences to further shift in the direction of free time and away from material consumption as concerns for planetary habitability build up.

Note also that we do not attempt to value the rise of gender equality, including rising employment rates for working-age women (up to 80% by 2100, i.e. the same level as for working-age men) and equal domestic labour time for women and men (see Figure 6 above). Given the ongoing change in norms and preferences, this is likely to bring additional well-being.

The main difficulty with this reasoning on average well-being, augmented GDP and the value of leisure (or the value of gender equality) is that such valuation processes are likely to vary a lot across individuals. Using the assumption that additional leisure hours bring on average the same marginal welfare as worked hours can be justified as a first approximation (and is likely to underestimate the average welfare value of leisure), but in practice it is clear that some individuals will value leisure more than average, while others will value leisure less than average. We return to this discussion below.

7.2. Adding the Value of Planetary Habitability (Subjective Well-Being & Output)

For simplicity, we restrict ourselves to two dimensions of planetary habitability valuation, namely the loss of subjective well-being due to global warming (independently from any possible income loss) on the one hand, and the loss of output and income due to global warming on the other hand. We will also discuss other forms of valuation, including the value of biodiversity and other biological services.

The loss of subjective well-being is the first obvious negative impact of global warming that needs to be considered. According to our projections, the Sustainable Convergence scenario is associated to much less severe global warming than the two other scenarios: 1.8°C rather than 4.1-4.2°C, i.e. a differential of 2.3-2.4°C.[59] This implies that humans will experience far fewer days with extreme temperatures in the SC scenario than in the PI and PC scenarios. The most direct impact of extreme temperature and climate events on welfare is a pure well-being effect. That is, independently from any possible income loss, it is painful to spend one additional day with very high temperature. The most severe form of well-being loss is of course the possibility of premature death due to high temperature (Carleton et al., 2022), but there are also relatively less severe forms of well-being losses hitting potentially many more people due to high temperature.[60] As a first approximation, we use a recent study by Dietrich and Nichols (2025) estimating the impact of the number of high-temperature days on self-reported well-being (as measured by a standard question on a life satisfaction on a scale from 1 to 10), using local-level variations in temperature in a large compilation of well-being surveys conducted in all world regions.[61] They find a large and significant negative impact of high-temperature days on well-being. In effect, according to their estimated coefficients, the projected global rise in the number of high-temperature days over the 2020-2030 period (corresponding to a global temperature rise of about 0.3 degrees) will lead to a global well-being impact equivalent to a 4% global income loss, with large variations across regions.[62]

For simplicity, we scale up linearly this average global effect to our projected temperature rise, implying that a differential of 2.3 degrees by 2100 would translate into a negative welfare impact equivalent to a 31% income loss for the PI scenario as compared to the SC scenario, i.e. a 45% income gain for the SC scenario as compared to the PI scenario.[63] We then use this +45% effect to scale up augmented per capita

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[59] Here we compare the SC scenario under fast decarbonization (FD) with the PC and PI scenarios under intermediate decarbonization (ID). The gap would be even larger if we were making the comparison with the PC and PI scenarios under slow decarbonization (SD) (current policies).

[60] These include worsening mental health (Obradovich et al., 2018; Burke et al., 2018), poorer sleep quality (Minor et al., 2022), lower cognitive performance (Park et al. 2020), water scarcity (World Bank, 2016), and increased conflict (Burke et al., 2015), to name a few.

[61] Dietrich and Nicolas (2025) use a total of about 1.7 million individual observations with self-reported well-being covering 160 countries over 40 years. They define high-temperature days (HTDs) as days with temperature above two standard deviations of historical mean, and they look at the impact on well-being of the number of HTDs in the past 30 days before the interview.

[62] The effect is as large as 10-12% in South & Southeast Asia, Subsaharan Africa and Latin America. This is the pure subjective well-being effect, controlling for any possible income effect. Dietrich and Nichols attempt to separate the income from the non-income effect and conclude with the data set and climate variations at their disposal that the income effect is relatively small (less than 5% of total effect). Note however that their data set is not necessarily the best suited to study the impact of climate shocks on output and income, given that the information on production and income that is available in the well-being survey is limited and not fully satisfactory.

[63] Here we use as comparison scenario the PI scenario with intermediate decarbonization trajectory, leading to 4.1 degrees warming by 2100, as compared to 1.8 degrees under SC scenario with fast decarbonization, hence a differential of 2.3 degrees. See online replication package for detailed computations and variants.

GDP in the SC scenario (see Figure 51a). Note that this simple linear scaling is likely to underestimate the true welfare effect, as large temperature rise are believed to have large non-linear multiplicative impacts, especially in the context of a 4 degrees rise in temperature.[64] Also our projections show that the temperature rise associated to the PI and PC scenarios is likely to be substantial higher than 4 degrees – in which case the extra welfare associated to the SC scenario will also need increased.

Regarding the impact of global warming on output, available estimates display very large variations. According to the recent study by Bilal and Kanzig (2026), a 1°C rise in global temperature leads to a long-run loss of about 20% of global GDP. As compared to previous studies exploiting local temperature variations, the main novelty of this study is that they use variations in global temperature and identify their impact on global GDP fluctuations over the 1870-2020 period. One advantage is that global temperature shocks allow in principle to identify the impact of extreme climate events, which might explain why Bilal and Kanzig find significantly larger effects than previous studies, with a social cost of the carbon ton around 1000-1500 Euros or more (rather than a few hundred euros). One limitation of the study is that the authors cannot fully disentangle the various mechanisms. I.e. high temperatures could lead to output loss because they make it more difficult to work efficiently (and/or certain economic activities can simply not take place any more), or because extreme climate events lead to the destruction of productive assets and infrastructures.[65] It should however be stressed that a number of estimates using alternative methods find significantly lower output losses than Bilal and Kanzig (2026), typically less than 5% of global GDP loss per additional degree (or less).[66] A recent meta-analysis by Howard and Sterner (2025) finds that damages could be in the range of 5-8% per additional degree. In other words, there is a wide variation in the estimates of climate damages depending upon methodology, assumed level vs growth effects, and time period studied. Considering this uncertainty and the fact that a scenario with temperatures in excess of 4 degrees in 2100 (as in PC and PI) are likely to come with larger damages than those usually considered, we assume 10% of global GDP loss per additional degree.

Again, for simplicity, we scale up this estimate and conclude that a differential of 2.3°C by 2100 would translate into a negative welfare impact equivalent to a 23% output loss for the PI scenario as compared to the SC scenario, i.e. a 31% output gain for the SC

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[64] Note also that the impact on SC vs PC scenarios is larger than on SC vs PI scenarios.
[65] To the extent that the reconstruction of these assets is included in GDP, the Bilal-Kanzig estimate might actually underestimate the true output loss associated to extreme climate shocks. Unfortunately the data at their disposal does not allow them to fully decompose these various effects.
[66] See Appendix Table R1.

scenario as compared to the PI scenario. We then use this +31% effect to scale up augmented per capita GDP in the SC scenario (see Figure 51a). Note that this simple linear scaling is again likely to underestimate the true welfare effect, given the very non-linear nature of climate effects.

When we put all the effects together, our conclusion is that augmented per capita GDP, including both the value of extra free time (leisure) and the value of planetary habitability (coming from the subjective well-being impact and the output effect), is as high to 227k euros in 2100 in the SC scenario, i.e. about twice as large per capita GDP in the alternative scenarios (see Figure 51a). To summarize, the Sustainable Convergence scenario appears to be twice more desirable than the alternative scenarios when we look at comprehensive well-being, while the opposite was true when we focused on traditional per capita GDP. This illustrates in a very striking manner why it is critical to go beyond GDP and to design alternative and more comprehensive indicators. In particular, according to our computations, all world regions – including Europe and North America/Oceania – have higher average well-being in the SC scenario than in the PI scenario (see Figure 51b).

Note that our conclusions are likely to be reinforced if we include other components for the valuation of planetary habitability. For instance, there exists a large literature attempting to estimate the value of biodiversity (in terms of equivalent income loss). The estimated values can be quite large and could significantly increase the total level of well-being associated with the SC scenario as compared to the PI and PC scenarios.[67] There also exists other estimates on the value of bio services rendered by forests, lakes, oceans, mountains, over and beyond their impact on climate change, and the associated estimates are again quite large and would significantly increase the gap in comprehensive well-being between the sustainable convergence scenario and other scenarios.[68]

These results hinge on explicit assumptions regarding the degree of substitutability between consumption, leisure, and environmental conditions. In Appendix D, we provide a more detailed discussion and consider alternative welfare functions – including specifications that impose zero or very limited substitution between material consumption and environmental quality – to assess the robustness of the welfare comparisons across scenarios and to clarify the role of substitutability assumptions. While magnitudes depend on the chosen welfare framework, the broader conclusion

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[67] See Dasgupta (2021) and IPBES (2022) for authoritative reviews.
[68] See, for example, de Groot et al. (2012), Constanza et al. (2014), Brander et al. (2015).

remains that a GDP-centered assessment alone obscures essential dimensions of long-run human well-being and planetary habitability.

7.3. Winners and Losers from the Sustainable Convergence Scenario

According to our findings, there should be unanimous support in favour of the SC scenario. That is, all countries – including in world's richest countries – are projected to have higher comprehensive well-being in 2100 under the SC scenario. For a given distribution of income, wealth and well-being within each country, all individuals from all percentiles – from the very poorest individuals up to the very richest – should all prefer the Sustainable Convergence scenario.

These optimist conclusions are interesting and suggestive, but unfortunately, they also suffer from a number of fragilities. The first problem is that these aggregate well-being estimates are based on the average valuation of free time and planetary habitability. While these computations might be true on average, they completely ignore the large heterogeneity which might exist in practice in the way different individuals value free time and planetary habitability. Typically, for someone who only cares about monetary income, and who derives little or no well-being from extra leisure or from planetary habitability, then it is clear that the Sustainable Convergence scenario is not their preferred scenario. Such an individual would naturally be better off in other scenarios, namely the Productivist Convergence scenario if they live in a poor country, and the Persistent Inequality if they live in a rich country.

The second problem is that the valuation of planetary habitability can vary systematically across countries. I.e. the welfare cost of global warming and extreme climate events is likely to be much larger in Subsaharan Africa, South & South-East Asia and Latin America than in Europe or North America. In our welfare estimates, we use the same average valuation of planetary habitability for all countries.[69] But if the inhabitants of Europe and North America do not care too much about global warming, because temperatures are cooler where they live, then from a purely selfish viewpoint they might be better off in the persistent inequality scenario. Of course, the inhabitants of countries with cooler temperature might also be concerned about other dimensions of planetary habitability, such as the value of biodiversity, forests, lakes, oceans and

[69] The estimates by Dietrich and Nichols (2025) do suggest that the well-being impact of high temperatures can be as much as 2-3 times larger than world average effects in Subsaharan Africa, South and South-East Asia and Latin America, and as little as 50% smaller than world aveage effects in Europe and North America. However, due to sample size limitations, regional-level and country-level coefficients are not always signficant (or significantly different from one another), so we choose to use only the average global effects in our welfare computations.

mountains as such. They might also be concerned about the well-being of others in poor countries, and/or they might fear the consequences of unequal development for political instability or migration pressures. But here again this will vary a lot across individuals, and how much various social groups share such concerns will be largely determined by the evolution of collective norms and public deliberation.

Finally, even if we ignore heterogeneity across individuals and countries in the valuation of leisure and the environment, and even if we take as given the conclusion that all countries have higher average well-being in 2100 in the Sustainable Convergence scenario, another problem is that this conclusion will generally not apply to the entire transition period 2025-2100. The reason is that the Sustainable Convergence scenario requires massive investment during the transition period (and especially between 2025 and 2070), while the returns to these investments (both in terms of productivity and planetary habitability) come only gradually, especially regarding the impact on the climate, which becomes fully visible at the end of the period. According to our projections, the SC scenario requires additional capital investment and human capital expenditure around 12% of world GDP by 2050 (see Figure 52). Additional needs in 2050 are projected to vary from about 8% of GDP in Europe/North America up to about 25% of GDP in Subsaharan Africa and South & Southeast Asia. Note that the compensation fund associated to the end of deforestation and the gradual process of reforestation is relatively small as compared to the total financing needs (about 1% of world GDP by 2050), but that this is still a very substantial amount, especially for certain countries and regions (up to 5% of GDP in Latin America).[70] Without a viable plan to finance all these additional investments and expenditures, it seems very difficult to build majority political support for SC.

The most natural solution would be to make the global rich finance a large part of these investments, and more generally to drastically compress the distribution of income and wealth within each country, so that in effect a large majority of the population (say, 90% or more) benefits from the SC scenario all along the transition period 2025-2100, both in the North and in the South, including from a purely monetary perspective, i.e. from the perspective of the subset of lower-income and middle-income individuals who might have little or no taste for extra leisure and planetary habitability, at least in the short-run. The key question is to determine which magnitude of income and wealth redistribution is necessary and how this can be achieved. This central issue is addressed in our companion paper (Bothe et al., 2026).

[70] The reforestation compensation was computed by estimating the value of foregone output in the food sector for the various regions.

8. Implementing Sustainable Prosperity: Quantity Controls and Other Tools

We now discuss the broader set of institutions and policies which would be necessary to implement the Sustainable Convergence scenario. We should make clear at the onset that we do not offer a full-fledged institutional and policy analysis in the context of this paper. At a more modest level, we start from the presumption that there exists a large diversity of institutional transformations and policy tools that can be used to implement the SC scenario, both at the national and global levels, and we shortly discuss some of the pros and cons of the various options.

In comparison to the PI and PC scenarios, the SC scenario is naturally the trajectory which requires the strongest change in policy trajectory, including extensive international cooperation, powerful social mobilization to reduce labor time and strong commitment to compress the share of material sectors and accelerate decarbonation. The issue of income and wealth redistribution is particularly critical to ensure widespread political support for the SC scenario, especially given the large transformation of production, investment and consumption structures, which might generate substantial discontent among lower-income and middle-income groups during the transition period. In our companion paper (Bothe et al., 2026), we show that this can be achieved by a mixture of global progressive taxation of income and wealth, sovereign wealth funds and structural transformation of the international trade and monetary system.

We stress that the SC scenario cannot be implemented simply by changing the tax system. Structural reforms of the global and national tax systems are obviously very important and will naturally play a crucial role, but they also need to be supplemented by many other policy tools and structural transformations, and in particular by the use of quantity controls and the extension of the public and non-profit sectors. This applies both to the reduction of labour hours and to the shift from material to immaterial sectors, as well to the transformation of energy systems and land uses at a global scale. We take these issues in turn.

8.1. Implementing the Reduction in Labor Hours

Historically, the reduction of labour hours was organized via national legislation and collective agreements in most countries and world regions over the 1800-2025 period. It is natural to expect that the same should happen over the 2026-2100 period.

Several remarks are in order here. First, it took enormous collective mobilization and social struggles historically to implement these legislative changes, and there is no reason to expect the process to be come easily in the future. Historically, the reduction of labour hours came with a more general collective movement aimed at improving the living conditions and real wages of workers – particularly low-wage and middle-wage workers – and it is also natural to expect the same for the future. Although we now face a new rationale for working time reduction – namely the compression of material footprint and the preservation of planetary habitability – we feel that it is still critical to emphasize the social dimension.

Note that the reduction of labour hours – down to about 1000 hours per year and per employed individual, i.e. 25 hours per week during 40 weeks and 12 weeks of paid vacations – can also play a powerful role to foster gender equality in economic and domestic labour time. However, this might not suffice, in which case other more proactive public policies would need to be implemented. For instance, one can think of a system of taxes and subsidies that would in effect transfer money income between spouses in households with highly unequal incomes and working times, and reward households with more equal sharing. Ultimately, the key objective is that collective norms reward gender equality so much that it is self-sustaining.

It should finally be emphasized that the reduction of labour hours always needs to be analysed through the lenses of its key objectives, namely personal emancipation and planetary habitability. For instance, labour hours need to be particularly reduced for workers who are in a hierarchical subordination position, but not necessarily for individuals who are in a position to organize their work in an autonomous way, especially if their economic activity carries little or no material footprint. E.g. there is little reason to reduce the working time of a music player or a yoga coach if they want to work more. Conversely, leisure time can be very damaging if it involves flying across the globe with enormous material footprint. This is why the compression of material sectors is a key objective in itself, which cannot be achieved by labor hours reduction alone.

8.2. Implementing the Shift from Material to Immaterial Sectors and the Changes in Food Habits

We now turn to the shift from material to immaterial sectors, i.e. the 30% reduction in the expenditure share of material sectors featured in the SC scenario. The main issue here is that the differential speed of technical progress across sectors makes it difficult to reduce the share of material sectors in total expenditure in volume terms, especially if one follows a market-driven development trajectory. In effect, due to faster technological change in material sectors, especially in manufacturing, the relative price of material goods has been falling over the 1970-2025 period. In the absence of any specific public policy (taxes, subsidies, regulations, etc.) which might be implemented in the future, we project that the same will happen to the structure of relative prices over the 2025-2100 period. In effect, the relative price of manufacturing was divided almost by two between 1970 and 2025 at the global level, and we expect it to be again divided by more than two between 2025 and 2100 (see Figures 53a-53b).[71]

In this context, a sharp fall in the volume share of material sectors (and specially manufacturing goods) in expenditure is unlikely to be a market outcome. According to past experience from the 1970-2025 period, the fall in relative price seems to have compensated satiation effects almost perfectly, so that the volume share of material sectors in total expenditure remained approximately stable at 53%. It makes sense to assume the same pattern will prevail in the future in the absence of any specific policy action, which is what we assume in the PC and PI trajectories, which in this respect can be viewed as business-as-usual trajectories. In contrast, the implementation of the SC scenario, including a 30% reduction in the share of material sectors in total expenditure, would require putting in place specific public policies (taxes, subsidies, price controls, progressive price schedules, vouchers, extended public sector, etc.).

In such a setting, the usual policy advocated by many economists would be a large corrective tax/subsidy scheme to raise the relative price of material goods and services relative to immaterial goods and services. In effect, this is like a massive carbon tax, i.e. a tax on the implicit CO_2 and other GHG emissions associated to various goods and services. This corrective tax could also take into account other dimensions of material footprint with a negative impact on planetary habitability.

In our view, however, there are several major problems with this corrective tax solution. First, the tax would need to be very large. I.e. in order to counteract the enormous long-run decline in the relative price of manufacturing goods (say, in comparison to education/health), we might need a tax of the order of 200-300% or more (see Figure

[71] We stress again that our assumptions on sectoral relative prices and relative productivity growth rates are bound to be fragile and provisional. The general observed pattern regarding material vs immaterial relative prices (especially manufacturing vs education/health) appears to be relatively robust, but several evolutions observed for other specific sectors are more uncertain and harder to predict. See e.g. the discussion in Appendix A for the case of relative price of housing and construction.

57b). Next, a common problem with corrective carbon taxes – especially when they become so large – is their adverse distributional effect. In theory, it is always possible to neutralize these adverse effects by distributing part or all of the revenue to lower income groups. However, in practice such promises often appear to be unfulfilled, so that low-income and middle-income taxpayers often have a very negative perception of these policies.

One way to address these concerns is to use non-linear corrective taxes (rather than flat corrective taxes). I.e. the corrective tax rate can vary with the quantity of food, manufacturing goods or energy purchased over a given time period, so as to implement progressive price schedules, including low prices for the first units purchased by households and much higher prices for large consumers. For instance, the first units of electricity consumption are affordable, but the following ones are not; the first airplane flights over one's lifetime are affordable, but the following ones are not; and so on. This is reminiscent of the famous progressive expenditure taxes advocated by Kaldor (1955) in a different context.[72] Like all progressive taxes, this requires more information than flat proportional taxes, but this does not imply that this is infeasible.

Another limit of the standard corrective tax logic is that it tends to put excessive emphasis on the price signals. In some cases, direct quantity controls or regulations can be more efficient than changing the price signal. E.g. a ban on thermal engines or a change in construction norm or a fixed number of airplane flights can have a stronger impact than a price signal. In addition, the profit-making logic does not always work very well in some of the key sectors which are scheduled to expend in the future in the SC scenario, especially education and health.[73] Rather than using a corrective tax/subsidy scheme to tax material sectors in order to subsidize the private production of education/health services, a better solution might be to raise tax revenue in general to expand the public education and health sector. In addition to the extension of the standard public sector – wherein local and/or national governments directly organize the production of free education and health services –, one could also use some of the extra tax revenue in order to finance education and health vouchers which could then

[72] Kaldor (1955) was concerned about the fact that some very rich individuals were able to escape progressive income taxation (with top tax rates higher than 80-90% at the time in the UK) by consuming out of their inherited wealth and/or untaxed family trust, an option not open to high-wage university professors like Kaldor, and he advocated sharply progressive expenditure taxation in order to counteract what he viewed as an immoral loophole of his country's tax system.

[73] E.g. total education and health costs tend to be substantially larger (as a fraction of GDP) in countries with a large private education and health sector – e.g. in the US or in Latin America as compared to Europe –, and available estimates suggest that these private education and health expenditures has a smaller positive impact on productivity or health indicators than corresponding public expenditures. See e.g. Bharti et al (2026).

be used to purchase services from the non-profit sector. This tax-and-voucher-sector logic could also be useful for other sectors, e.g. one might think of using "organic food' vouchers to allow households to purchase food from local producers, subject to a certain number of conditions. As compared to the standard market-driven corrective tax logic, one additional advantage of the tax-and-public-sector and tax-and-voucher-sector policy tools is that they can allow for more direct margins of action in order to compress the income and wealth scale in the corresponding sectors and production units (see Bothe et al., 2026 for further analysis along these lines).

8.3. Implementing the Structural Changes in Energy Systems and Land Uses

We finally come to the structural changes in energy systems and land use patterns. Here again one can think of a large diversity of policy tools in order to implement these changes. In principle these objectives could be achieved by relying on standard profit-making private actors and an appropriate system of corrective taxes/subsidies and/or some form universal carbon price.

The problem with this market logic is that it may not deliver the required outcomes, both in terms of equity and efficiency. Existing evidence suggests that it can be useful to have a diversity of actors – including public and non-profit actors – in order to produce energy. In case we rely excessively on standard private capitalist actors, historical experience suggests that it is more difficult to pursue sustainability objectives and to resist to profit-making logics (see e.g. Chancel (2025) and Chancel and Mohren (2025)). Needless to say, it is very difficult to determine the ideal mix between public, non-profit and private actors, and the best response might well vary over time and across countries.

The other key issue to take into account is the financing of the energy investment and of the changes in land-use patterns. As we already noted, investment needs – both in terms of capital investment and human capital expenditure – are scheduled to be particularly large in Sub-Saharan Africa and South and Southeast Asia, and the opportunity costs of reforestation (and the end of deforestation) will fall mostly on these same regions – and even more so on Latin America. In order to analyze the financing of these various components, it is critical to put the distributional dimension at the centre of the analysis. If we think only in terms of aggregate country-to-country transfers, investment flows and net foreign wealth position, it is very difficult to say anything about the political acceptability of these scenarios. These issues of investment finance and distributional implications are addressed in our companion paper (Bothe et al., 2026).

9. Concluding Comments and Research Perspectives

In this paper, we have analyzed multisector development scenarios whereby all world countries converge to the same per capita GDP by 2100, and we have explored under what conditions this is compatible with the preservation of planetary habitability (in particular with limiting global anthropogenic temperature rise to below 2°C). In our benchmark scenario, all countries reach 60k euros in per capita GDP in 2100 (using fixed 2025 PPP prices), close to today's levels in the world's richest countries. We have shown that this is compatible with planetary habitability only under very strict conditions, including major structural transformation, a drastic reduction in work hours, a large shift from material to immaterial sectors, a massive investment plan in low-carbon infrastructures, reforestation and human capital, and ambitious inequality compression. Our main conclusion is that sustainable development requires a decisive move toward sufficiency, material degrowth, structural transformation and equality: electrification of energy systems alone will not suffice. In effect, this research can be viewed as an attempt to offer a plausible, multisector quantitative analysis of material degrowth at the global level over the 2026-2100 period.

We should stress that our analysis has many limitations which should be addressed in future research. First, this paper offers a multisector country-level analysis. We repeatedly stress the importance of within-country inequality, but we did not introduce explicitly within-country distributions into the analysis. This is what we do in our companion paper (Bothe et al., 2026), which allows us to address the central issue of political acceptability of the Sustainable Convergence scenario.

Next, we emphasize again that our work relies on a relatively crude description of the production sector and the possible changes in the technology and input-output matrices. We use a multisector model based upon 8 main sectors (and up to 25 sectors once we introduce all the energy subsectors). We have assembled a new homogenous database on input-output matrices based upon these sectors and covering the entire world – broken down into 57 countries and residual regions – over the 1970-2025 period. On this basis, we have made what we view as the most natural assumptions regarding the evolution of the technology – as summarized by input-output matrices – over the 2026-2100 period. It should be clear, however, that these assumptions are relatively crude, and that by doing we might have overlooked a number of very important potential transformations. For instance, it might be possible in some cases to shift to very different production techniques in future decades, for instance more traditional techniques using less material inputs but more human labour. This might be true in material sectors like agriculture, construction and manufacturing, as well as in supposedly immaterial sectors like education and health, which can also use very different techniques and input structures. With such a shift in techniques, it might be the case that we use more human labour (thereby reducing the pace of labour time reduction over the 2026-2100 period) but that this allows us to significantly accelerate the reduction of material footprint and the preservation of planetary habitability. More research would be needed in order to provide credible quantitative estimates of the implied changes in input-output structures and resulting material patterns. We hope that the highly imperfect framework developed in this research – as well as the corresponding online database – will prove to be useful to other researchers willing to contribute to this collective process and develop new work in this direction.

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Technical Appendix

Appendix A. Housing Services and Construction

The results reported in Tables 4 and 5 (section 2) illustrate how we treat the special case of the construction sector. With our sectoral classification (see Table 1), the value-added VA_{ict} of the construction sector (i=2) includes two very different components: housing services and construction (including housing construction and other construction). Housing services correspond to the rental value of all existing housing units (owner-occupied or tenant-occupied, including private, public and social housing units),[74] while housing construction and other construction correspond to the construction of new housing units and other structures. In standard national accounts, housing services are classified as part of real estate activities, together with real estate agencies and other similar services. Attempting to relate to the basic needs perspective, however, it makes more sense to deduct housing services from real estate services and to treat them as a separate item within the housing/construction sector, especially given that housing services are a very large subsector (about 8% of global GDP in 2025, vs about 6% of global GDP for the construction subsector) and corresponds to a key spending item (housing rent) and a central component of well-being – or lack thereof – for many households.[75]

It is also worth noting that from a standard national accounting perspective, housing services are produced with little labour input (they represent for the most part the pure rental value of the capital services provided by housing units), so that hourly GDP in this subsector appears to be extremely high (more than 15 times higher than average

[74]According to available estimates, the world housing capital stock is worth 248% of world gross domestic product in 2025, including about 90% owned by households (222% of GDP, including both owner-occupied and tenant-occupied) and 10% owned by corporate and government sectors (resp. 19% and 7%), with large variations over time and across countries. See Bauluz et al (2025, Figure 10 and complete series in online appendix and on wid.world). Note that public housing entities are classified in corporate sector if they apply significant rent (typically more than half of their ressources).

[75]Existing national accounts series do not usually report complete separate estimates for housing services within real estate activities. Therefore we proceed as follows: we start from available series on housing services produced by the household sector (which are available in a large number of countries and were recently homogenized by Dietrich et al (2025)) and then use available series on the composition of the housing stock (Bauluz et al (2025)) in order to estimate total housing rent from all institutional sectors (household, corporate and government); we find that this represents on average about 90% of real estate activities at the global level (with some variations across countries and regions, which are partly due to the fact that available decompositions of national accounts series by institutional sector are generally less complete and homogenous than decompositions by production sector). For simplicity, we define housing services as being equal to 90% of real estate activities in our benchmark series (and leave the remaining 10% in other services). We also made robustness checks with country-varying and/or time-varying ratios, and this has very little impact on our findings. These estimates can be revised and updated in the future as more detailed decompositions become available.

hourly productivity).[76] In effect, housing services appear to be even more capital-intensive as the energy sector. This is partly artificial, however, since these housing services would not exist without the labour used to build these housing units. It is worth noting that if we put both housing services and construction into the housing/construction sector, then hourly productivity in this sector appears to be quite large – about 30% higher than average productivity. In contrast, if we only look at the construction subsector strictly speaking (in effect ignoring the housing services made possible by cumulated past construction work), then hourly productivity appears to be fairly small – about 40% smaller than average productivity (see Table 4). We return to this issue when we compare the evolution of sectoral productivities. Finally, note that the production of housing services involves relatively small intermediate consumption input (around 25-30% of output),[77] and that housing services are rarely used as intermediate input by other sectors (see Table 5).

It is also interesting to note that we observe a large rise in the relative prices housing/construction sector between 1970 and 2025 (see the Figures on relative prices discussed in section 8). It is possible that this reflects factors that are partly temporary and might not happen again with the same magnitude in the future.[78] Note also that the 1970-2025 rise of relative price of housing/construction reported is the combination of a very sharp rise for construction and a near-stability for housing services.[79] The fact that the relative price of housing services (i.e. housing rent) almost does not rise over 1970-2025 period is itself the combination of several contradictory effects (including a sharp rise in large agglomerations, especially in Europe, and a fall in less densely populated territories). At the global level, the GDP share of housing services rises a bit (by about 20-30%) over the 1970-2025, but this reflects mostly a rise in volume (i.e. a real rise in per capita square meters, housing quality, etc., which has been than average volume aggregate growth), and a very small rise in relative price (less than 5% at the global level, and about 10-20% in Europe). In effect, housing values double relative to GDP between 1970 and 2025, but housing rent rises relatively little (as a fraction of GDP), so that housing returns are roughly divided by two (see Bauluz et al (2025, Figures 1 & 31-32)). Several factors can potentially explain why

[76] We assume the same labour input structure as for real estate activities as a whole.
[77] Existing series do not always report separate estimates for intermediate consumption input related to housing services. Available estimates suggest that intermediate inputs (in the form of maintenance and repair services, insurance, property management services, etc.) represent about 20% of output (gross housing rent), i.e. a level that is relatively close to intermediate consumption observed for real estate activities as a whole. See e.g. Mayerhauser and Reinsdorf (2007). We therefore apply the same average input structure as that observed for real estate activities, and we do the same for the labour input (maintenance, property management services, etc.).
[78] See the discussion above on relative productivity trends.
[79] See Appendix Figures C1a-C2b.

households accepted such a big rise in housing values but not housing rent (including a rising a rising taste for home ownership and rising wealth concentration). Regarding construction prices, it is possible that the construction sector captured part of the housing price boom by setting higher construction prices (translating into low measured productivity), and/or that the lack of sufficient technical progress and available space as compared to huge rise in volume of housing (GDP was multiplied by 6 in volume at the global level between 1970 and 2025, including by 3-4 in Europe and North America/Oceania, and the volume of housing services even more according to available series). Given this enormous space pressure, maybe the most surprising fact is why housing rents did not rise even more. In any case, the conditions are likely to be different over the 2025-2100 period, e.g. due to much lower population growth.

Appendix B. Data: Sources and Harmonization

The WSEED database integrates a large number of data sources, which required extensive harmonization efforts to produce consistent long-run series across countries, sectors, and variables. This appendix describes the sources and methods underlying each variable group. The macroeconomic variables are discussed first, followed by the emissions and land-use data, which differ in their source structure and coverage period. The database will be revised and updated in future versions. Planned improvements include the integration of GTAP 12, ICP microdata allowing for more refined sectoral PPP adjustments, and additional country-level sources.

B1. Macroeconomic Variables

On the macroeconomic variables, we first describe the general harmonization and extrapolation procedures that apply across variables, before turning to variable-specific source descriptions covering GDP, GNE, sectoral price deflators and PPP adjustments, and finally input-output coefficients, trade, and gross output.

B1.1. Harmonization

All macroeconomic variables are harmonized using a shares-based approach. For each variable, sectoral values are divided by total economy GDP from the same source to obtain sector shares, the shares are harmonized across sources, and absolute values are then reconstructed by multiplying the harmonized shares by the harmonized economy-wide totals. For GDP and labour hours, we draw directly on the newly harmonized series following the WID country classification from Nievas and Piketty

(2025) and Andreescu et al. (2025), respectively, which serve as the benchmark total-economy series. For other variables, such as gross national expenditure, where no harmonized WID-consistent totals yet exist, sectoral values are usually expressed as shares of GDP from the same source, and the resulting harmonized shares are subsequently rescaled by the harmonized GDP series. This procedure ensures internal consistency across variables and prevents level differences between sources from introducing spurious trends. Throughout, we enforce that subcomponents sum to their aggregates; where inconsistencies arise, we give priority to the aggregates, which typically carry higher data quality.

For each variable, sources are assigned a priority order based on data quality and coverage. The level of the series for each country is anchored to the highest-priority available source. Lower-priority sources contribute year-on-year growth rates used to extend the series forward and backward in time, which prevents discontinuities arising from methodological differences across sources. All sources are individually inspected by country and variable, and outliers are excluded from the harmonization. In ambiguous cases, additional sources are consulted.

Several sources do not disaggregate sectors sufficiently to match the eight-sector classification and require additional treatment. The long-run WIOD does not separately identify Education/Health from some of the items in the Leisure/Culture sector, reporting them as a combined aggregate. We split this aggregate using the earliest available WIOD shares to anchor the split, then backcast Education/Health on the trend of the combined sector, while Leisure/Culture follows a composite trend of the combined sector and those long-run WIOD industries that can be separately assigned to that category, such as accommodation and food services. Similarly, the UN Main Aggregates use a seven-sector classification that does not differentiate between these two sectors. Given this limitation, the source receives the lowest priority overall and is used only for a small number of low-income countries for which no other source is available; in these cases, the combined sector is split using an approximate two-thirds leisure and one-third public services ratio, which approximates the average observed in low-income countries covered by other data. A further exception arises in some historical sources that do not report real estate activities, the basis of Housing Services covering imputed and actual rents, as a separate category. In these cases, we use the trend of the next broader available category, typically a subset of Other Services that combines real estate with legal, consulting, or similar activities, to extend the Housing Services series.

For countries with changing territories over the covered period, e.g. Germany, Ethiopia, and Sudan, we take the absolute levels of the most recent territory definition and extend them historically using the growth rates of the most comparable available territory. For Germany this means relying on West Germany for the pre-unification period; for Sudan, on the joint territory prior to the 2011 partition.

B1.2. Extrapolation

To produce a global panel covering all 57 countries and regions over the full 1970–2025 period, we apply a three-step extrapolation procedure where observed data are unavailable. All extrapolated series are inspected manually and compared to historical accounts to ensure the results are plausible.

For countries lacking sectoral data over long periods (typically pre-1995) or with no data at all, we assign values using regional average shares weighted by each country's national aggregates, computed at the level of the nine world regions. These shares are applied at benchmark years (1970, 1995, and 2020), with linear interpolation between benchmark years and observed data points. The resulting shares are multiplied by observed country totals. When no country total exists either, we extrapolate the sectoral variables relative to national GDP and then rescale by observed GDP.

For series where only a small number of years are missing at the beginning or end of the period, we estimate compound average annual growth rates over the first or last ten years of observed data and apply them to extend the series. This approach is also used to project most values for 2024 and 2025, which will require updating as new data become available.

The nine residual regions aggregate data from countries not individually listed among the core 48, e.g., "Other Western Europe." To create those aggregates, we first harmonize and extrapolate series for all 216 countries individually using the two steps above, and then aggregate them to the regional totals. As with individual countries, we ensure that sectoral values sum to the region's economy-wide totals and, where necessary, adjust subcomponents to be consistent with their aggregates, giving precedence to the latter.

Data coverage is strongest for sectoral GDP, for which some sectoral data is available for all 216 WID countries. Coverage is most limited for A-matrices and trade, which are derived exclusively from inter-country input-output table. Nonetheless, the combined sources cover over 90% of global demand, inputs and trade for the post-1995 period without extrapolation.

B1.3. Gross Domestic Product

Total economy GDP in both current and constant prices, together with total economy deflators, is drawn from Nievas and Piketty (2025), who provide updated series for all 216 countries in the World Inequality Database. These aggregate values are then disaggregated into eight sectors using sectoral GDP shares in current and constant prices from a hierarchy of sources. Among all variables in the database, GDP has the strongest data coverage and does not require regional extrapolation for any country.

Where available, we draw on the WIOD and the long-run WIOD from the Groningen Growth and Development Centre, which provide input-output tables for around 35 countries in both current and previous-year prices up until 2014 (Timmer et al., 2015; Woltjer et al., 2021). Previous-year price series are converted into constant prices through chain-linking. Country and year coverage, particularly for the Global South, is extended using the Economic Transformation Database (ETD) and its Transition Economies extension on former Soviet Union economies, the African Sector Database (ASD), and the Ten-Sector Database (TSD) (Kruse et al., 2023; Hamilton and de Vries, 2025; de Vries et al., 2015; Timmer et al., 2015a). We additionally incorporate UN Official Country Data, drawing only on country-year entries with complete industry coverage. Finally, where no other source is available (primarily for some smaller, low-income economies) we rely on the UN Main Aggregates, which cover 219 territories using a seven-sector classification and are treated as the lowest-priority source throughout, for the reasons described above.

Overall, sectoral GDP data are available for all 216 WID territories. Combining the harmonized sectoral shares with the total GDP series from Nievas and Piketty (2025) yields absolute sectoral values that are fully consistent with the total economy aggregates.

B1.4. Gross National Expenditure: Consumption and Investment

Gross national expenditure (or Final Demand) captures a consumption perspective on economic activity, recording all expenditure on goods and services not used as intermediate inputs in further production. Globally, investment accounts for roughly one quarter of final demand and consumption for three quarters, a composition that has remained broadly stable since 1970 (see Appendix Figure 29). Consumption comprises both household and government consumption, while investment covers gross fixed capital formation and changes in inventories. We enforce the identity that consumption and investment sum to gross national expenditure throughout the database. At the sector level, gross national expenditure is assigned to the industry of completion, that is, the last industry to modify a product before it reaches the final user. An exception applies to trade and transport margins: only the value added of these activities is counted as their own final demand, while the remaining value is attributed to the last producing industry of the supply chain (Lequiller and Blades, 2014).

Comparable cross-country data on sectoral consumption and investment are considerably scarcer than for value added (Herrendorf et al., 2014). We rely primarily on inter-country input-output (ICIO) tables, which jointly provide substantial country and year coverage. The main sources are the WIOD and long-run WIOD tables, the OECD tables and the FIGARO database. ICIO tables are particularly suited to this purpose because they distinguish between intermediate and final uses and detail cross-border flows, making it possible to observe sectoral consumption and investment at the country level. Since most ICIO tables include a "Rest of the World" residual that is typically extrapolated rather than directly observed, we do not use these residuals. Instead, we construct our own residual regions from actual country-level observations for the countries beyond the 48 core countries, supplemented by regional averages where country data are unavailable.

B1.5. Sectoral Deflators & PPP Adjustments

The database includes separate sectoral deflators for value added and for expenditure, which can differ meaningfully from one another: value-added deflators primarily reflect price changes in the production step of a given sector, while expenditure deflators are shaped by the full upstream supply chain, including the prices of all intermediate inputs used across the production network. Total economy deflators and PPP adjustment factors are taken from Nievas and Piketty (2025) and serve as the benchmark against which sectoral price series are anchored.

Sectoral deflator series are constructed in two steps. We first build sectoral inflation series using a chain-linking approach that draws on the current-price and previous-year-price data available in the ICIO and national accounts sources, converting year-on-year price changes into consistent constant-price series. We then account for sectoral output weights and compute sectoral relative price series, defined such that the weighted average across sectors is consistent with total economy inflation.

For purchasing power parity adjustments, most series in the database are expressed using the headline PPP exchange rates from Nievas and Piketty (2025). We additionally provide a specification using sectorally adjusted PPP series. The economic rationale is that traded sectors tend to exhibit more similar prices across countries, while non-tradable sectors show larger cross-country price dispersion, so that economy-wide PPP conversions, which average across all sectors, can distort comparisons of sectoral consumption levels. Currently, we use the publicly available data from the 2021 ICP round. However, limitations in the publicly available data only permit an approximate mapping to our sector classification, so sectorally adjusted PPP series are provided as an additional specification rather than as the benchmark. A particular difficulty for our classification is that this data reports housing and energy expenditures in a combined aggregate category, making it impossible to construct separate sectoral PPP adjustments for these two sectors with current public data. Future revisions intend to draw on the disaggregated ICP microdata, which would allow for a more reliable and complete set of sector-specific PPP series.

B1.6. A-Matrices, Trade, and Output

Input-output coefficients (A-matrices), gross output, and bilateral trade flows by sector have the most limited data coverage of all variables in the database and are accordingly derived from a narrower set of sources. For the recent period, we rely on the OECD inter-country input-output tables, which offer broad country coverage from 1995 onward. For the period prior to 1995, the long-run WIOD provide the primary source of A-matrices and gross output data, albeit for a smaller set of countries. The FIGARO database does not substantially extend country or time coverage relative to the OECD tables but is used as an additional source to cross-check the OECD series and identify country-level outliers. Because the set of countries observed directly is more restricted for these variables than for GDP or GNE, residual regions are not constructed from remaining individual country sources but are instead assigned the weighted regional averages of all directly observed countries in the region.

To model the energy transition in the projection framework in greater detail, we use data from GTAP to disaggregate both the A-matrix and the gross output and final demand of the energy sector into the fourteen energy subsectors described in Section 2. Since GTAP data are limited in time coverage, they are used only for recent years as a starting point for the projections and are not incorporated into the historical database. Specifically, we use GTAP 11, which covers the year 2017, as the basis for assumptions about the disaggregation of the energy and electricity sectors in 2025. The resulting values are cross-checked against IEA data, which do not carry the same sectoral disaggregation but can be compared at the aggregate energy level. GTAP 12, with more recent time coverage, is expected to become available this year and will be integrated into the projection input data in a future revision of the database.

B1.7. Population

Population series by country and at the global level are taken from Gomez-Carrera et al. (2024). Over the study period from 1970 to 2025, the dataset primarily draws on the 2024 revision of the UN World Population Prospects.

B2. Emissions and Land-Use Data

Sectoral CO2 and GHG series for 2000–2022 are constructed by combining data from WIOD (42 countries, 2000–2016) and FIGARO (45 countries, 2010–2022), rescaled to match country-level aggregates from the Global Carbon Project (CO2) and EDGAR (total GHG, excluding emissions from land-use change). Where sectoral data are unavailable, emissions are imputed using regional average emission intensities. Country-level series are then aggregated to core territories, and non-CO2 GHG is derived as the residual between total GHG and CO2 at the sectoral level.

Historical regional land-use data is obtained from Our World In Data and from the FAO. We model emissions from land-use change using carbon content per hectare and per region, as described in Appendix C.

Appendix C. Land-Use Emissions and Forest Regrowth Model

Emissions from land-use change are estimated by combining changes in land area by category with the carbon content of an average hectare in each region. We infer high and low estimates of biomass stock (i.e. carbon content) per hectare, region by region, from the IPCC (Table 4.4 and following tables, IPCC 2019).[80] Forest regrowth uptake

[80] 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Vol. 4, Agriculture, Forestry and Other Land Use). IPCC.

rates are derived from empirical above-ground biomass accumulation in secondary forests and interpreted as landscape-average net regrowth rates consistent with IPCC/GCP accounting (see Appendix Table 5, tables A5c-g).

Land Use Emissions

Our model can be described as follows. Let r index regions and t index years. In each region, forest area $F_{r,t}$, grazing land $G_{r,t}$, and cropland $C_{r,t}$ evolve over time according to scenario-specific growth assumptions and food-system requirements.

Cropland requirements are linked to population growth through the historically estimated elasticity of cropland with respect to population. Let $P_{r,t}$ denote population and $\varepsilon_{C,P}$ the elasticity estimated over 1990–2020 such that:

$$\ln C_{r,t} - \ln C_{r,t_0} = \varepsilon_{C,P}\left(\ln P_{r,t} - \ln P_{r,t_0}\right)$$

Projected cropland requirements absent yield changes are given by:

$$C_{r,t}^{req} = C_{r,2025}\left(\frac{P_{r,t}}{P_{r,2025}}\right)^{\varepsilon_{C,P}}$$

To account for lower yields under sustainable agricultural practices, we introduce a yield penalty parameter ϕ reflecting the observed productivity gap between conventional and best-practice organic systems.[81] Using a central estimate ϕ=0.13, effective cropland demand becomes:

$$C_{r,t} = \frac{C_{r,t}^{req}}{1-\phi}.$$

In tropical regions, reforestation and cropland expansion are reconciled primarily through reductions in grazing land and, where necessary, through adjustments in wild grasslands. Empirically, most historical tropical deforestation has been associated with

[81] See Seufert et al. (2012).

grazing expansion, and in the sustainable scenario we observe that roughly 90% of grazing land reductions are absorbed by forest expansion over the projection horizon. Wild grasslands absorb part of cropland expansion where grazing reductions are insufficient, and conversely may expand if both cropland and forest increase more slowly than grazing declines.

Forest-area changes are translated into CO2 emissions and removals using region-specific biomass stocks and regrowth parameters obtained from IPCC publications. We infer high and low tC/ha estimates region by region.[82] Forest regrowth uptake rates are derived from empirical above-ground biomass accumulation in secondary forests, converted to CO_2 and interpreted as landscape-average net regrowth rates.[83]

Annual forest losses and gains are defined as:

$$Loss_{r,t}=\max(F_{r,t-1} - F_{r,t}, 0),$$
$$Gain_{r,t}=\max(F_{r,t} - F_{r,t-1}, 0).$$

Gross deforestation emissions are:

$$E^{def}_{r,t}= Loss_{r,t} \cdot S_r / 1000$$

with areas in Mha and emissions expressed in $GtCO_2$.

Forest regrowth $R^{reg}_{r,t}$ is modeled using a three-phase cohort structure reflecting the empirical shape of biomass accumulation which we describe in the Appendix.

Net forest-related CO_2 emissions are:

$$NetCO2^{forest}_{r,t} = E^{def}_{r,t} - R^{reg}_{r,t}.$$

[82] See Table 4.4 (and following tables) in Intergovernmental Panel on Climate Change (2019). Our Biomass stock represent above and below ground biomass (AGB+BGB) per hectare.
[83] We observe that these rates are typically ≈1.3–3.0 tC ha^{-1} yr^{-1} over long-run to early regrowth phases. For each region, we convert average forest biomass stock typically expressed in tC/ha ($s_{C,r}$) into tCO2/ha (S_r) via $S_r = s_{C,r} \times 3.667$. For regrowth values in secondary forests, See Poorter et al. (2016).

Additional land-use components—peat drainage and fires, wood harvest and other transitions—are projected from recent Global Carbon Project averages under BAU and gradually decline under the sustainability scenario.

Forest regrowth model

Let $u_{2,r}$ denote the average regrowth uptake rate (tCO_2/ha/yr), derived from empirical estimates of secondary forest growth consistent with IPCC and Global Carbon Project accounting. We define late-stage uptake as:

$$u_{3,r}=m\cdot u_{2,r}, m=0.5,$$

and determine early-stage uptake $u_{1,r}$ such that cumulative uptake over the recovery horizon T_r equals the biomass stock:

$$20u_{1,r}+40u_{2,r}+(T_r-60)u_{3,r}=S_r.$$

Thus,

$$u_{1,r}=\frac{S_r-40u_{2,r}-(T_r-60)u_{3,r}}{20}.$$

Cumulative forest gains in each age band are:

$$C_{1,r,t}=\sum_{\tau=t-19}^{t} Gain_{r,\tau},$$

$$C_{2,r,t}=\sum_{\tau=t-59}^{t-20} Gain_{r,\tau},$$

$$C_{3,r,t}=\sum_{\tau=t-T_r+1}^{t-60} Gain_{r,\tau}.$$

Annual regrowth removals are then:

$$R_{r,t}^{reg}=\frac{u_{1,r}C_{1,r,t}+u_{2,r}C_{2,r,t}+u_{3,r}C_{3,r,t}}{1000}.$$

Appendix D. Alternative Welfare Computations

While the augmented GDP presented in Section 7.2 has the advantage of accounting for leisure time and climate damages in a transparent manner, it implicitly involves making some strong assumptions. It imposes perfect substitutability between consumption, leisure and the environment, assumes constant marginal utility from both consumption and leisure, and does not discount future periods. To relax these assumptions, we present here a more formal welfare evaluation framework using three alternate utility functions.

D.1. Alternate Utility Specifications

The first specification, which we refer to as "additive", assumes effective income (adjusted for climate damages) and leisure enter additively in the utility function:

$$u(t) = \log(\hat{y}_t) + \chi \frac{{l_t}^{1-\sigma}}{1-\sigma}$$

$\hat{y}_t$ = effective income (adjusting for climate change damages)

l_t= total leisure hours

χ = relative weight on leisure

σ = leisure curvature

The additive nature of the specification implies that the marginal utility from income and leisure and independent of each other. The leisure curvature parameter (σ) controls the degree of diminishing returns in leisure. As a benchmark we use a value of 1 (implying a log function on leisure) such that both income and leisure have the same degree of diminishing returns. The relative weight on leisure (χ) is calibrated from 2025 baseline data. Note that this assumes the observed leisure-labour hours split in 2025 is optimal, which may in fact be a conservative choice if we believe that workers would actually prefer to work less but need collective legislation in order to achieve this objective (which is what happened over the 1800-2025; see e.g. Andreescu et al 2025). One way to model this situation is to assume a higher relative weight on leisure (χ), which we do below. Another modelling option, which is more complex but arguably more satisfactory, is to assume that workers also derive utility from their relative income. As a consequence, they tend to work too much, and they need collective legislation and collective organizations (like trade unions) in order to reach the optimal balance between income and leisure (Goerke & Hillesheim, 2013). It would be interesting to explicitly include such effects in future extensions of the present work.

The second specification, which we refer to as "CES", bundles effective income (again, adjusted for climate damages) and leisure into a constant-elasticity-of-substitution (CES) composite:

$$u(t) = \frac{1}{\rho}\log[\alpha\, \hat{y}_t^{\rho} + (1-\alpha)\, l_t^{\rho}]$$

$\rho = \frac{\varepsilon-1}{\varepsilon}$ with ε = elasticity of substitution b/w adjusted income and leisure

α = weight of income in utility

The CES specification allows for complementarity or substitutability between income and leisure. When $\varepsilon < 1$, income and consumption are complements and when $\varepsilon > 1$, they are substitutes. Our default is to assume $\varepsilon = 0.8$ but we will also try higher values. The relative weight of income (α) is calibrated per-region by equating the marginal rate of substitution between leisure and income to the hourly income.

In both these specifications, it is *effective* income that enters the utility, i.e. income scaled down for climate damages. This is operationalized via the following:

$$\hat{y}_t = y_t \,.\, \exp(-(\varphi + \delta)\, \Delta T_t)$$

φ = output losses from 1°C temperature rise

δ= well-being losses (income equivalent) from 1°C temperature rise

y_t = 'raw' income pathway

Given that all climate damages are routed via income in the above two utility specifications, they implicitly assume perfect substitutability between income and the environment. This assumption, however, is unlikely to hold if there are some climate damages (tipping points, irreparable biodiversity losses etc.) that cannot be compensated for by increased incomes. To relax this assumption, we introduce a third specification, which we refer to as "ecological", where an index of environmental quality directly enters the utility function:

$$u(t) = \frac{1}{\eta}\log[\beta\, \tilde{y}_t^{\eta} + (1-\beta)\, E_t^{\eta}] + \chi \frac{{l_t}^{1-\sigma}}{1-\sigma}$$

$\tilde{y}$ = $[\{y_t \,.\exp(-(\varphi)\, \Delta T_t)\} /\ y_{2025}]$

η = $\frac{\epsilon - 1}{\epsilon}$ with ϵ = elasticity of substitution b/w income and environment

β = relative weight on income over environment

This specification aggregates an income index (adjusted for only output losses and normalized by the 2025 income levels) and an environment index (E) into a composite CES with leisure entering additively as in the first specification. The environment index, ranging from 0 to 1, is defined as the following:

$$E_t = \frac{1}{1 + \kappa\, \Delta T}$$

The parameter κ controls how fast the environmental index degrades with every additional temperature of warming. For instance, if we set κ to equal 0.5, then at 2 degrees of additional warming, the environmental index would be halved. On other hand, if we calibrate κ to about 0.15 (roughly based on the well-being losses from Dietrich and Nichols (2025)), the environmental index will drop to about 0.75 with 2 degrees of warming. Regarding relative weights of income and environment within the CES, we set β to equal 0.5, giving equal weight to both (noting that both the income index and the environment index take on values of 1 in 2025).

Overall, the three utility specifications impose different assumptions about the degree of substitutability / complementarity between income, leisure and the environment, which in effect embed implicit normative and ethical choices. While the advantage of this approach is that it allows us to be more explicit about these choices, the downside is that the number of parameters involved also increases and makes the results sensitive to these various choices. Our preferred specification would be the last of three which explicitly controls the substitutability between income and the environment, but leisure still enters additively implying the quality of the environment does not affect the utility of leisure. Clearly, there are various directions such an exercise could be taken in but we restrict ourselves to these three utility functions as useful alternate benchmarks.

D.2. Key results

We analyze the welfare implications at the global level as well as the regional-level comprising 8 world regions. We then compute lifetime welfare over the 2025–2100 horizon, discounting future well-being, and summarise the comparison as an income equivalent (IE): the permanent percentage change in income that would make a person indifferent between the two scenarios.

It is important to note at the outset that the exact magnitudes at the regional level vary based on the choice of regional-level calibration parameters (like, for eg., the leisure weight) as well as heterogenous climate damages (much larger damages in poorer tropical countries). Nonetheless, the main result we find is that the SC scenario turns out to be welfare superior to the PC and PI scenario under each of the three specifications, both for the world as well as for each of the eight world regions individually. The SC advantage is largest in regions that face high climate vulnerability and benefit most from additional free time.

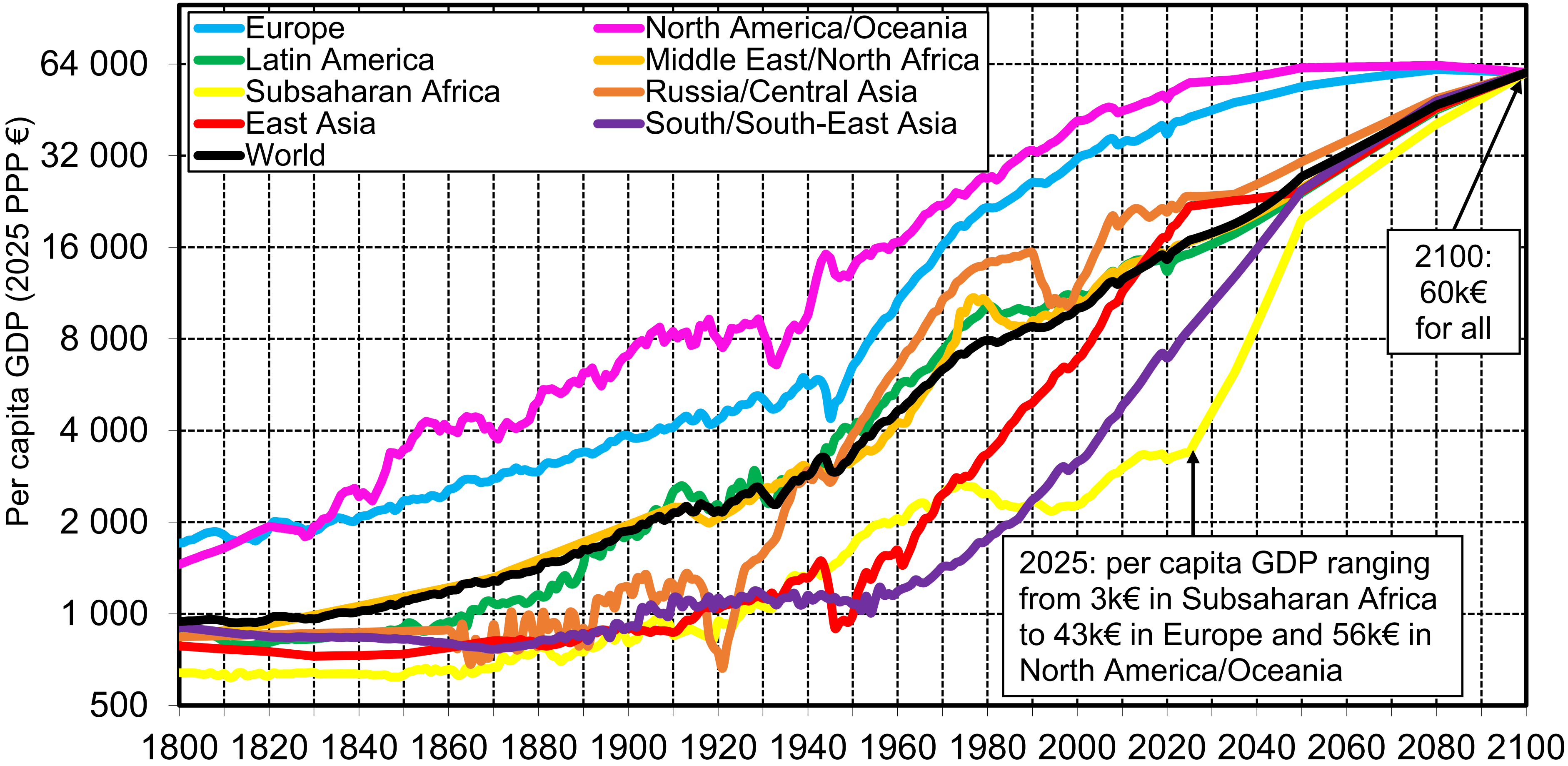
At the world-level, the welfare gains from SC relative to PC are equal to a 27% IE based on the ecological specification. This is assuming a 2% discount rate, leisure curvature (σ) of 1, elasticity of substitution between income and environment (ϵ) of 0.5, and the relative weight on income within the CES also at 0.5. Similarly, our benchmark estimate for the additive specification is 12% permanent income-equivalent advantage in the SC relative to PC. Among the three specifications, the SC gain appears to be smallest, but still positive, in the CES specification over income and leisure. Nonetheless, there too the welfare advantage is positive for all world regions.

As expected, if we increase the relative weight on leisure (χ) in the additive and ecological specifications, the welfare gains under SC over PC and PI would be further amplified. The same applies if we reduce the substitutability between income and environment (ϵ) or increase relative weight on environment inside the income-environment CES composite in the latter (β). For instance if we set χ to 8 and reduce both β and ϵ to 0.25, we find that the welfare gains under SC could be as large as 80% IE under the ecological specification.

The main result of SC welfare dominating PC and PI scenarios is robust to a broad range of plausible discount rates, leisure curvature and CES parameters. What appears to matter more are the climate damage parameters (φ, δ) and how they are operationalized. In the ecological specification, setting output and well-being damages to as low as 2-3% still delivers a substantial 20% permanent income-equivalent welfare advantage in SC over the PC scenario. On the other hand, in the additive specification, setting output and well-being damages to 2-3% would reverse the conclusion: PC would welfare dominate SC marginally at the world-level. In other words, if environment enters the utility function directly, then even small damages are hard to compensate for via higher incomes.

In summary, for a broad class of utility functions and a range of plausible parameter choices, we find that the SC scenario welfare dominates the PC and PI scenarios in all world regions over the rest of this century. Further, these conclusions are likely to be reinforced if we include other components for the valuation of planetary habitability including, for instance, the value of biodiversity and biological services.

Fig. 1a. Is Prosperity for All Compatible with Planetary Boundaries?



Interpretation. In this research, we ask whether high living standards for all (say, with per capita GDP around 60k€ PPP 2025 by 2100) are compatible with planetary boundaries. We find that the 60k target is possible only under very strict conditions: drastic reduction in labour hours, major shift from material to immaterial sectors, change in food habits and decarbonization of production. **Sources and series**: wseed.world (A1a)

Fig. 1b. Or Do We Need A Little Degrowth for Rich Countries?

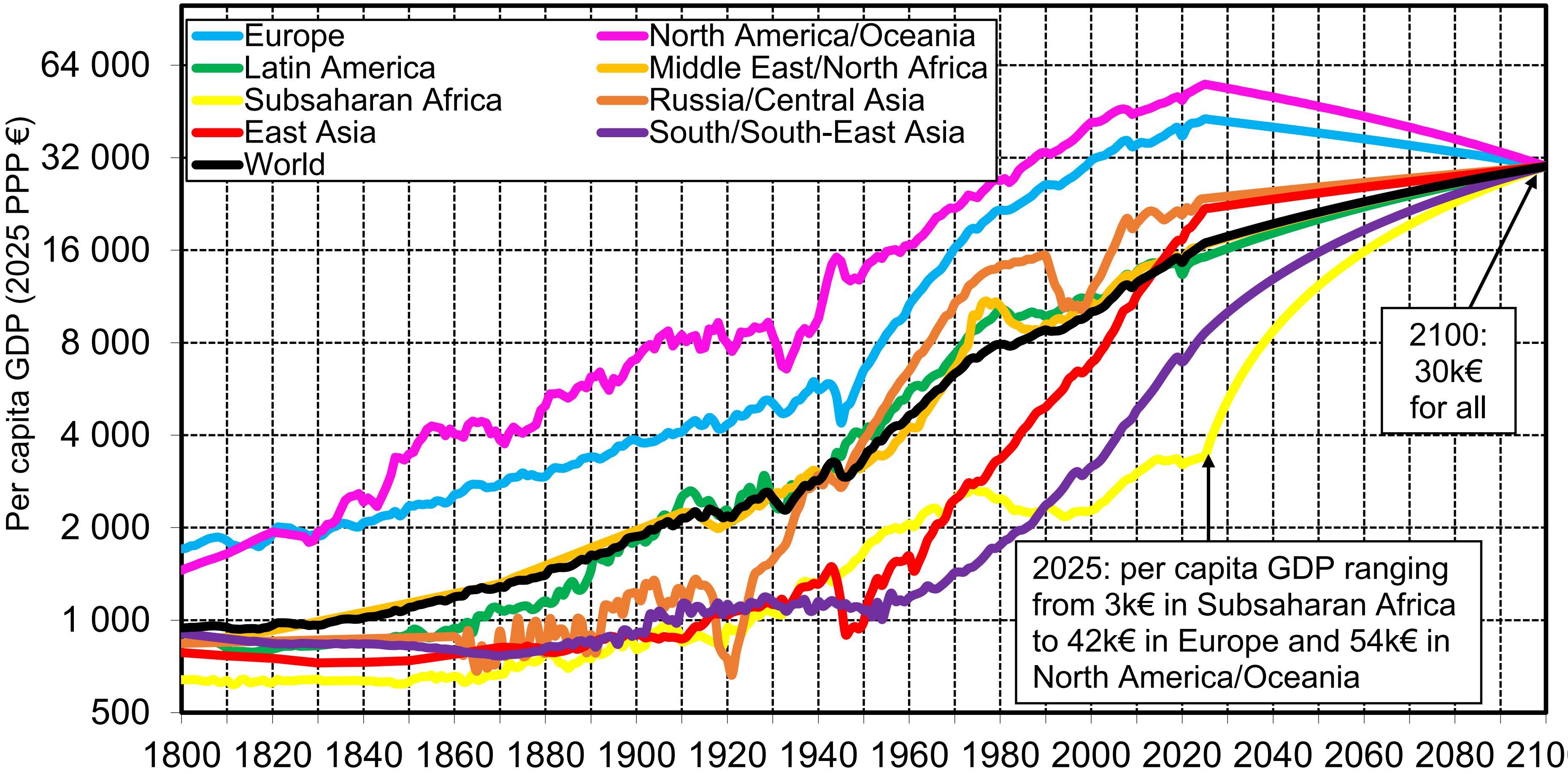


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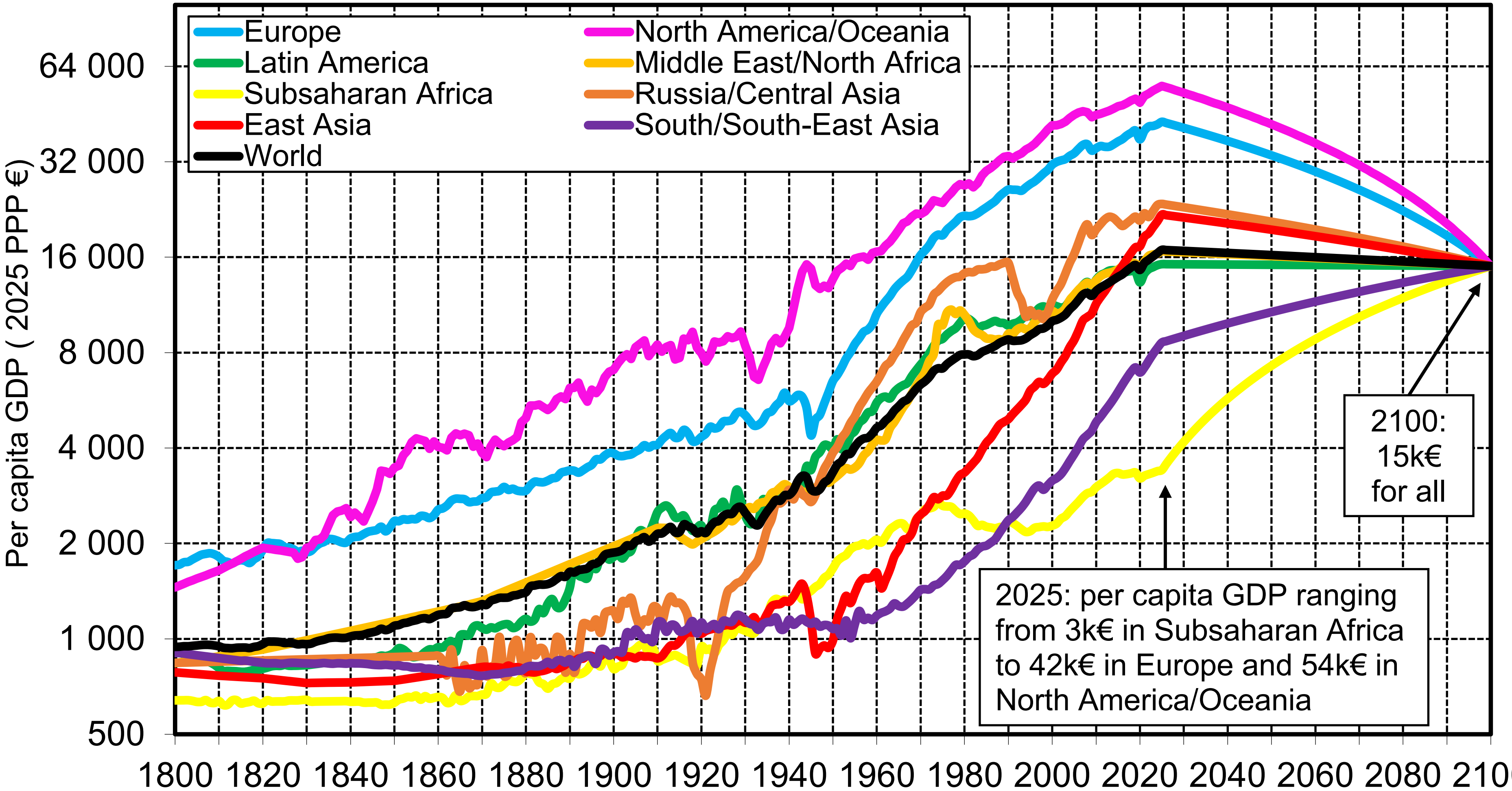
Fig. 1c. Or a Large Degrowth for Rich Countries?



Interpretation. In this research, we ask whether high living standards for all (say, with per capita GDP around 60k€ PPP 2025 by 2100) are compatible with planetary boundaries. We find that the 60k target is possible only under very strict conditions: drastic reduction in labour hours, major shift from material to immaterial sectors, change in food habits and decarbonization of production. **Sources and series**: wseed.world (A1c)

Table 1. The Classification of Economic Sectors Used in the World Sectoral Economy-Environment Database (WSEED)

	Sector	ISIC 3 Code	ISIC 4 Code	Included Sectors and Industries
Material Sectors	**Food** (incl. agriculture & processed food)	A+B+D15-16	A+C10-12	Agriculture; fishing; forestry; Manufacturing of food, beverages, tobacco
	Housing/Construction (incl. housing services and construction)	F + K (part)	F + L (part)	Housing services; Construction
	Manufacturing (incl. textiles, electronics, cars, etc.)	D exc. D15-16	C exc. C10-12	All manufacturing except food products: e.g. textiles, electrical equipment, machniery, vehicles, paper, chemicals, metals, plastics, etc.
	Energy (incl. mining)	C + E	B + D+E	Electricity, oil, gas; Water treatment and supply; Sewerage and waste managment; Mining and quarrying
	Transport (incl. train, bus, air, boat, etc.)	I	H	Land, water, air transport; pipelines; warehousing
Immaterial Sectors	**Education/Health** (incl. other public services)	L+M+N	O+P+Q	Education; Human health; Residential care and social work activities; Public Administration: public order, defense, foreign affairs
	Leisure/Culture (incl. shops, restaurants, bars, hotels, movies, books, etc.)	G+H+O+P	G+I+J+R+S+T	Wholesale & retail trade; Accomodation & food service activities ; Repair; Publishing, movie, broadcasting; Arts, museum, libraries; Sports & recreation
	Other services (incl. legal, financial, consulting, computing, architecture, etc.)	J+K	K+L+M+N	Financial, insurance, pension, IT, consultancy; Real estate (exc. Housing services); Legal, Accounting; Scientific R&D; Advertising, architectural, technical

Description. This research relies on the construction of a novel eight-sector database to analyse structual transfromation and track sectoral emissions for the 57 WID core territories from 1970 to 2025. All sources are harmonized to eight equivalent sectors. These eight sectors (five "material" and three "immaterial") are partly based on ISIC classifications (International Standard Industrial Classification for all Economic Activities, United Nations), with a number of changes and adjustments. The distinction between material and immaterial sectors is based upon input intensity: material sectors have more input intensity and material footprint than immaterial sectors. This differs from traditional classifications and is arguably more suitable for the study of sustaiable development and well-being. The extent to which the immaterial sectors are truly immaterial – and/or can become even more so in the future – is a central issue which is closely investigated in this research. **Source:** wseed.world (A0a)

Table 2. The Structure of Economic Sectors & Energy Subsectors Used in WSEED

	Sector
Material Sectors	**Food** (incl. agriculture and processed food)
	Housing/Construction (incl. housing services and construction)
	Manufacturing (incl. textiles, electronics, cars, etc.)
	Energy (incl. mining)
	Transport (incl. train, bus, air, boat, etc.)
Immaterial Sectors	**Education/Health** (incl. other public services)
	Leisure/Culture (incl. shops, restaurants, bars, hotels, movies, books, etc.)
	Other services (incl. legal, financial, consulting, computing, architecture, etc.)

	Energy Subsector
Energy (incl. mining)	Coal
	Gas
	Oil / Liquid Fuels
	Electricity
	Minerals
	Water & Waste

	Electricity Subsector
Electricity	Coal Power
	Gas Power
	Oil Power
	Other Power
	Nuclear Power
	Hydro power
	Solar power
	Wind power
	Electricity transmission and distribution

Description. For the projection framework and emission analysis, it is essential to model the energy sector in more detail. Thus, we employ additional data sources to break up the energy sector into subsectors. Thereby, we proceed on two levels breaking up energy and then the elctricity sector further. We always asure that the aggregate is the sum of the subsectors. In our energy/emission projections, we work with the most disaggregated input-output structure whereby we model the energy transition as a shift to the electricity sector as well as to low-carbon sources within the energy and the electricity sector. **Source**: wseed.world (X1)

Table 3. Geographical Coverage of the WSEED Database	
East Asia (5)	China, Japan, South Korea, Taiwan Other EASA
Europe (11)	Britain, Denmark, France, Germany, Italy, Netherlands, Norway, Spain, Sweden, Other W.EUR, Other E.EUR
Latin America (6)	Argentina, Brasil, Chile, Colombia Mexico, Other LATAM
Middle East/ North Africa (8)	Algeria, Egypt, Iran, Morocco, Saudi Arabia, Turkey, UAE, Other MENA
North America/ Oceania (5)	USA, Canada, Australia, New Zealand Other NAOC
Russia/ Central Asia (2)	Russia Other RUCA
South/South-East Asia (9)	Bangladesh, India, Indonesia, Myanmar, Pakistan, Philipinnes, Thailand, Vietnam, Other SSEA
Sub-Saharan Africa (11)	DR Congo, Ethiopia, Kenya, Ivory Coast, Mali, Niger, Nigeria, Rwanda, Sudan, South Africa, Other SSAF

Description. Our sectoral database covers all 57 WID core territories (48 main countries + 9 residual regions) over the 1970-2025 period. The 48 main countries were chosen on the basis of population size, GDP, regional representativity and data availability. Throughout the 1800-2025 period, the 48 main countries cover about 85-90% of the world population and GDP, while the 9 residual regions cover 10-15%. Some of the series (including population and sectoral GDP) are also available for all 216 WID core countries, but some of the key series (including input-ouput matrices and labour hours by sector) are only available for the 57 core territories in a consistent manner. See wid.world/codes-dictionary/#country-code for the full list of WID 216 core countries. **Source:** wseed.world (A0b)

Table 4. Sources used for the World Sectoral Economy-Environment Database (WSEED)		
Variables	**Description**	**Sources**
Sectoral GDP & Sectoral Prices	Total Economy GDP and Deflator from WID, sectoral shares newly harmonized for all 57 core territories	WID National Accounts Database
		World Input-Ouput Database
		Long-run WIOD
		ETD (Economic Transformation Database)
		ETD Transition Economies
		African Sector Database
		10-Sector Database
		OECD Inter-Country Input-Output Tables (2023 Release and new PYP tables)
		UN Data: National Accounts Official Country Data (Tables 2.1 - 2.4)
		UN Data: National Accounts Estimates of Main Aggregates
		International Comparison Program (ICP) Public Data
Sectoral Labour Hours	Total Economy from Andreescu et al. (2025), sectoral shares newly harmonized for all 57 core territories	ILOSTAT: mean weekly hours
		ETD (Economic Transformation Database)
		ETD Transition Economies
		African Sector Database
		10-Sector Database
		ILO Modelled Estimates
Expenditure, A-matrix & Trade	Harmonization of total and sectoral expenditure (total, consumption, investment), imports, exports and technical coefficients	FIGARO
		OECD Inter-Country Input-Output Tables (2023 Release and new PYP tables)
		World Input-Output Database
		Long-run WIOD
		GTAP (Global Trade Analysis Project)
GHG Emissions	Sectoral production and final demand emissions for all 57 WID core territories	FIGARO
		Global Carbon Project
		GTAP (Global Trade Analysis Project)
Land Use	Land-use by regions and for the world	FAO
		OWID
Population	Latest version of WID-UN Population Series for all 216 WID core countries	WID Population Series
		UN World Population Prospects 2024

Description. This research relies on the construction of a novel eight-sector database to analyse structual transfromation and track sectoral emissions for the 57 WID core territories from 1970 to 2025. The table shows the key sources for used for each variable to create the harmonized series. All sources are harmonized to the equivalent sectors. All monetary variables are expressed in PPP Euros either in current prices or constant 2025 prices but can also be transformed in MER using real exchange rates. **Source:** wseed.world (A0c)

Table 5. The Structure of Global Expenditure:
Sectoral Per-Capita Gross National Expenditure, Final Consumption and Investment (2025)

		Total Economy	**Material sectors**	Food	Housing/ Construction	incl. Housing services	incl. Construction (housing & other)	Manufacturing	Energy	Transport	**Immaterial sectors**	Education Health	Leisure Culture	Other Services
Per-Capita GNE (Gross National Expenditure)	(thousands PPP € 2025)	**16.9**	**8.9**	1.8	3.5	1.2	2.3	2.5	0.5	0.6	**8.0**	3.7	2.9	1.4
	(% total)	**100%**	**53%**	10%	20%	7%	13%	15%	3%	3%	**47%**	22%	17%	8%
Per-Capita Final Consumption Expenditure	(thousands PPP € 2025)	**12.3**	**5.2**	1.7	1.2	1.1	0.0	1.3	0.5	0.5	**7.1**	3.6	2.5	1.0
	(% total)	**100%**	**42%**	14%	10%	9%	0%	10%	4%	4%	**58%**	30%	20%	8%
Per-Capita Investment Expenditure	(thousands PPP € 2025)	**4.6**	**3.7**	0.1	2.3	0.1	2.2	1.2	0.1	0.1	**0.9**	0.1	0.4	0.4
	(% average)	**100%**	**80%**	1%	50%	1%	48%	27%	1%	1%	**20%**	2%	9%	9%

Interpretation. Per capita GNE (Gross National Expenditure) amounts to about 16.9k Euros PPP at the world level in 2025 (i.e. 1.4k Euros per month). In 2025, 73 percent of GNE is consumption and 27 percent is investment. **Source:** wseed.world (G1)

Table 6. The Structure of Global GDP: Sectoral Value-Added & Productivity (2025)

		Total Economy	**Material sectors**	Food	Housing/ Construction	incl. Housing services	incl. Construction (housing & other)	Manufacturing Goods	Energy	Transport	**Immaterial sectors**	Education Health	Leisure Culture	Other Services
Per capita GDP	(thousands PPP € 2025)	**16.9**	**8.1**	1.4	2.4	1.3	1.1	2.5	1.1	0.7	**8.8**	2.7	3.2	3.0
	(% total)	**100%**	**48%**	8%	14%	8%	6%	15%	7%	4%	**52%**	16%	19%	18%
Per capita economic labour hours	(hours)	**850**	**480**	239	88	3	85	87	20	47	**370**	88	227	55
	(% total)	**100%**	**56%**	28%	10%	0.4%	10%	10%	2%	5%	**44%**	10%	27%	6%
Productivity (hourly GDP)	(PPP € 2025)	**20**	**17**	6	27	426	13	28	56	16	**24**	30	14	54
	(% average)	**100%**	**85%**	30%	135%	2146%	63%	143%	284%	79%	**120%**	152%	70%	273%

Interpretation. Per capita GDP amounts to about 16.9k Euros PPP at the world level in 2025 (i.e. 1.4k Euros per month). Per capita economic labour hours (i.e. excluding domestic labour) amount to about 840 hours per year, so that average productivity – as measured by hourly GDP – is approximately 20 Euros. Hourly productivity varies enormously across sectors, reflecting differences in technology, labour composition and capital intensity, as well as as institutional factors and disparities in bargaining power between sectors and countries. **Source:** wseed.world (F1a)

Table 7. The Global Input-Ouput Matrix in 2025

Each column reports intermediate consumption inputs used by each sector as % of its total output	**Total Economy**	Food	Housing Services	Construction	Manufacturing Goods	Energy	Education/ Health	Leisure/ Culture	Transport	Other Services
Food	**5%**	35%	0%	1%	3%	1%	2%	5%	1%	0%
Housing Services	**2%**	0%	3%	1%	0%	0%	2%	4%	1%	2%
Construction	**2%**	0%	6%	8%	0%	1%	2%	1%	1%	1%
Manufacturing Goods	**16%**	6%	2%	29%	41%	6%	7%	6%	8%	5%
Energy	**8%**	3%	2%	5%	9%	38%	3%	3%	15%	2%
Education/Health	**1%**	0%	1%	0%	0%	0%	4%	1%	1%	1%
Leisure/Culture	**7%**	8%	2%	7%	9%	4%	7%	10%	9%	6%
Transport	**3%**	2%	0%	3%	3%	3%	2%	4%	13%	1%
Other Services	**9%**	3%	10%	7%	4%	4%	8%	10%	9%	23%
Total Intermediate Inputs	**52%**	**57%**	**26%**	**61%**	**69%**	**57%**	**36%**	**44%**	**58%**	**42%**
Sector Share in Ouput	100%	10%	5%	8%	22%	8%	12%	16%	4%	15%
Sector Share in GDP (value-added)	100%	8%	8%	6%	15%	7%	16%	19%	4%	18%
Sector Share in Intermediate Energy Use	100%	4%	1%	5%	25%	41%	5%	7%	8%	3%

Interpretation. In order to produce 100€ of education/health. one spends 36€ in intermediate inputs (including 7€ in manufacturing goods and 3€ in energy). In order to produce 100€ in manufacturing goods, one spends 69€ in intermediate inputs (including 41€ in manufacturing goods and 9€ in energy). The material footprint of "immaterial" sectors is smaller than that of "material" sectors, but it should still be reduced substantially in order to become truly "immaterial". **Source:** wseed.world (O1a)

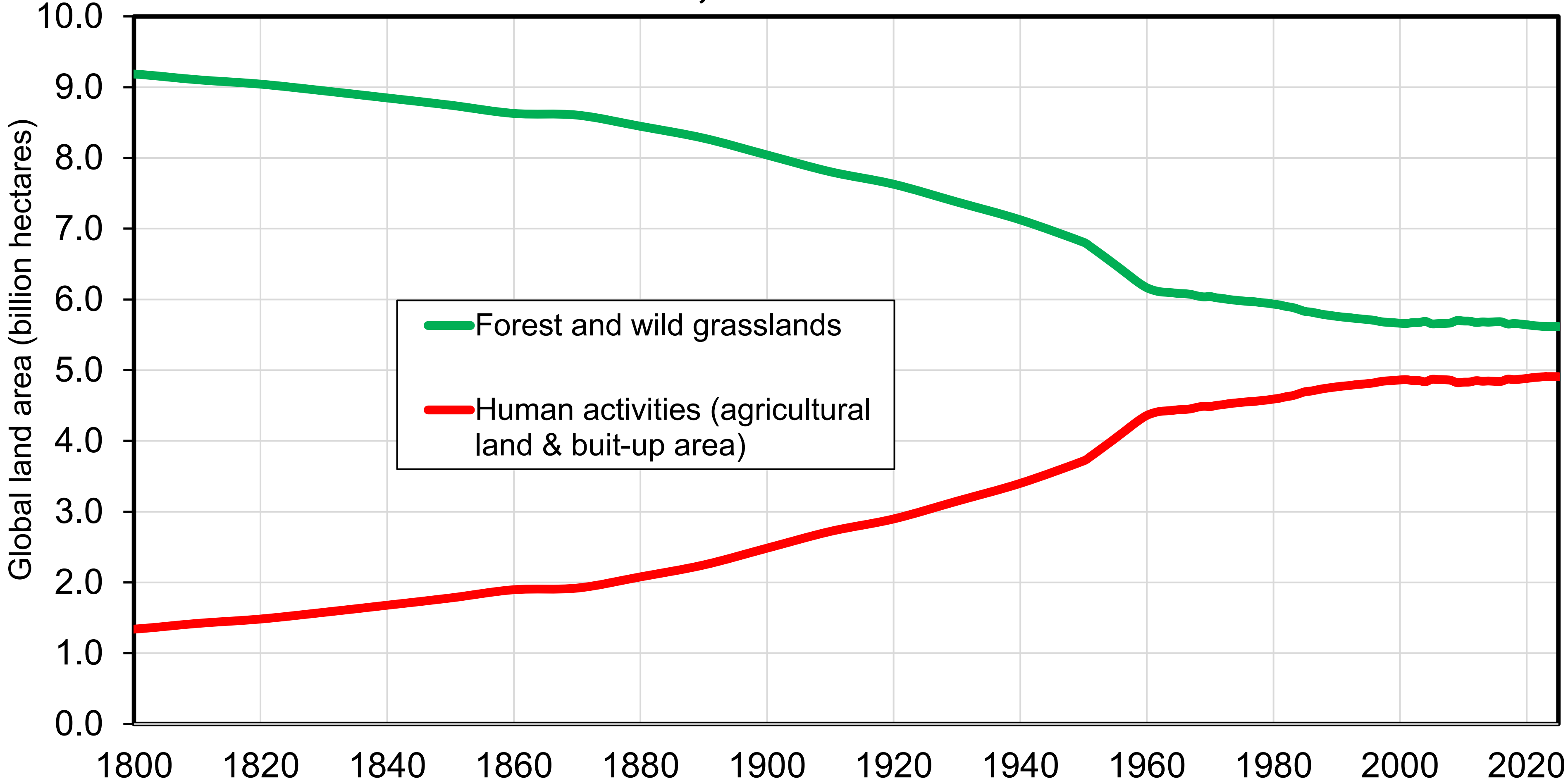
Table 8. Global land area (2025)

	Area (billion hectares)	% total
Total land area	**14.8**	***100%***
incl. Human activities	***4.9***	***33%***
incl. Built up area	*0.1*	*1%*
incl. Grazing land (cattle)	*3.2*	*22%*
incl. Cropland	*1.6*	*11%*
incl. Forest & wild grasslands	***5.6***	***38%***
incl. Forests	*4.1*	*28%*
incl. Wild grasslands & shrubs	*1.5*	*10%*
incl. Other Barren Land *(mountains, deserts..)*	***4.3***	***29%***

Interpretation. Global land area amounts to about 14.8 billions hectares in 2025, including approximately 33% used by human activities (mostly grazing land and cropland), 38% in forests and wild grasslands and 29% in other barren land (mountains, deserts, etc.).

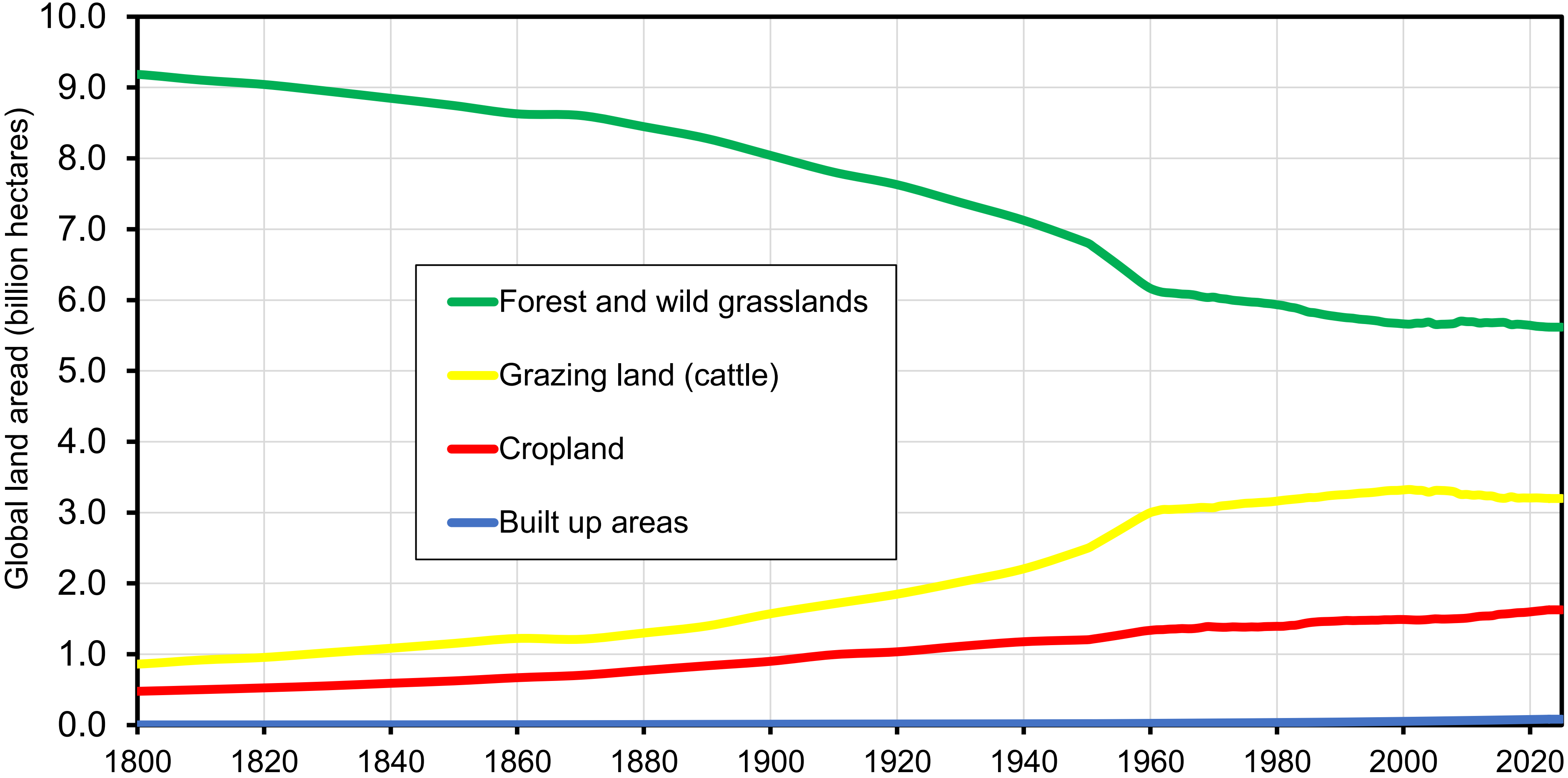
Sources and series: wseed.world (U1a)

Fig. 2a. Global Land Use, 1800-2025: the Decline of Forest & Wild Grasslands, the Rise of Human Activities



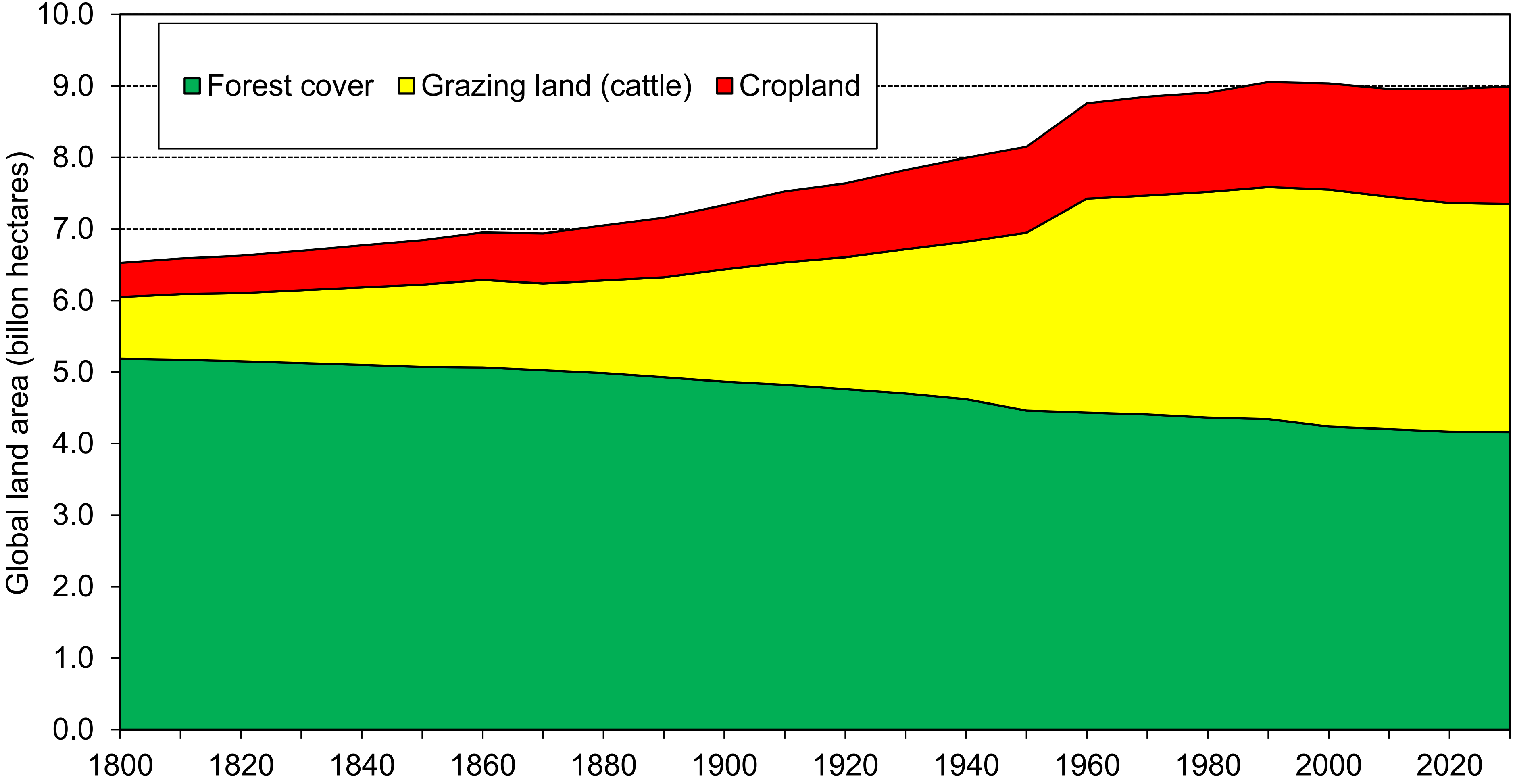
Interpretation. Global land area covered by forest & wild grasslands declined from about 9.2 billion hectares in 1800 (incl. 5.2 for forest and 4.0 for wild grasslands) to 8.0 billion in 1900 (incl. 4.8 and 3.2) and 5.6 billion in 2025 (incl. 4.1 and 1.5). Land area covered by human activities rose from 1.3 billion in 1800 to 2.5 billion in 1900 and 4.9 billion in 2025 (including 4.8 for agricultural land and 0.1 for built-up area). **Note.** Total land area also includes about 4.3 billion in other barren land (mountains, deserts, etc.), which has been approximately constant over time. **Sources and series**: wseed.world (U1a)

Fig. 2b. The Great Transformation of Global Land Use 1800-2025: The Key Role of Grazing Land (Cattle)



Interpretation. Global land area covered by forest and wild grasslands declined from about 9.2 billions hectares in 1800 to 8.0 billions in 1900 and 5.6 billions in 2025. In the meantime land area covered by human activities rose from 1.3 billions in 1800 to 2.5 billions in 1900 and 4.9 billions in 2025 (including 3.2 for grazing land, 1.6 for cropland and 0.1 for built-up area). **Note.** Total land area also includes about 4.3 billions in other barren land (mountains, deserts, etc.), which has been approximately constant over time. **Sources and series**: wseed.world (U1b)

Fig. 2c. The Replacement of Global Forest Cover by Agricultural Land (Grazing Land and Cropland), 1800-2025



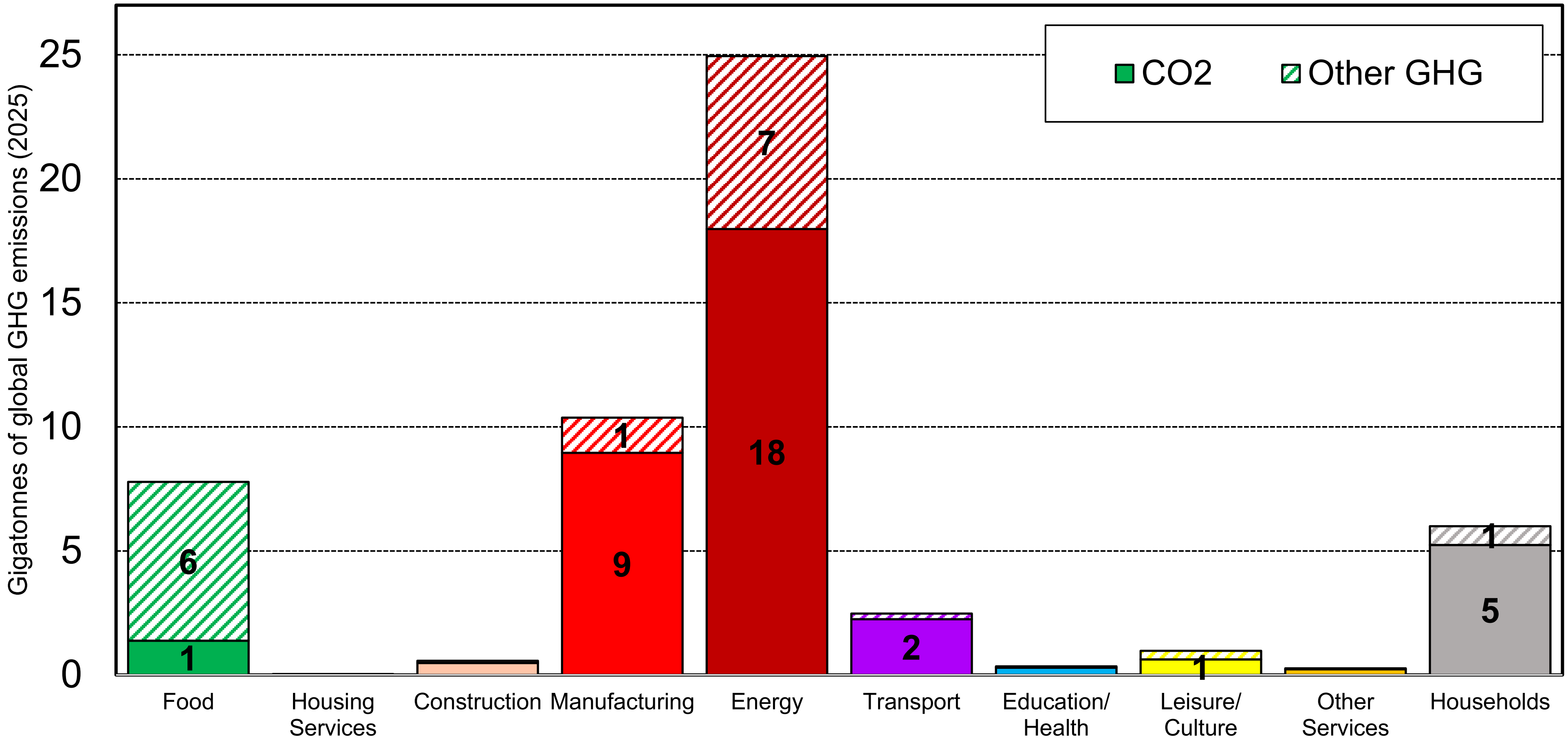
Interpretation. Global forest cover dropped from about 5.2 billions hectares in 1800 to 4.1 billions in 2025. In the meantime, agricultural land rose from 1.3 billions in 1800 (including 0.8 in grazing land and 0.5 in cropland) to 4.8 billions in 2025 (including 3.2 in grazing land and 1.6 in cropland). The expension of agricultural land was made possible both by the decline of forest cover (deforestation) and the fall of wild grasslands.
Sources and series: wseed.world (U1c)

Table 9. Global GHG Emissions in 2025

	Emissions (GtCO2e)	Emissions (% Total)
All sectors	**56.7**	**100%**
Fossil Fuels Energy	***39.8***	***70%***
incl. Fossil CO2 (coal/oil/gas burning)	*36.2*	*64%*
incl. Fossil other GHG (coal/gas production)	*3.6*	*6%*
Agriculture & Land Use Changes	***9.9***	***18%***
incl. Agr. Land Use CO2 (deforestation)	*3.6*	*6%*
incl. Agr. Land Use other GHG (cattle)	*6.3*	*11%*
Industrial Processes	***6.9***	***12%***
incl. Industry CO2 (cement, etc.)	*2.7*	*5%*
incl. Industry other GHG (chemicals, waste)	*4.2*	*7%*

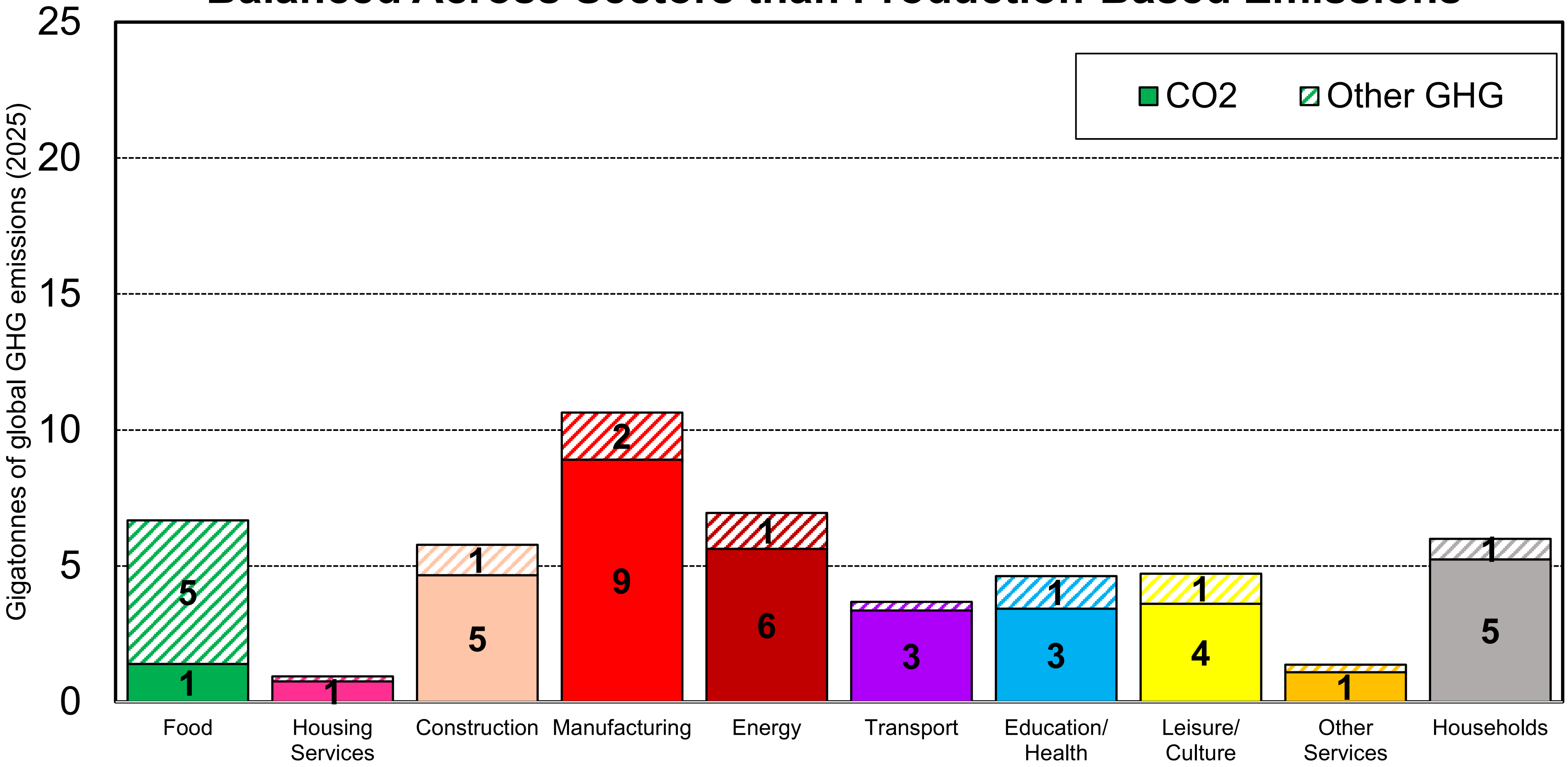
Interpretation. In 2025, 70% of GHG (greenhouse gases) emissions come from fossil fuels energy, 18% from agriculture & land-use changes and 12% from industrial processes. **Note.** For details on categories see online replication package. All greenhouse gases (CO2 and other GHG: methane (CH4), nitrous oxide (N2O), etc.) are expressed in gigatonnes of CO2 equivalents. **Sources**: wseed.world (X2)

Fig. 3a. Production-Based Global GHG Emissions Are Massively Concentrated in Material Sectors



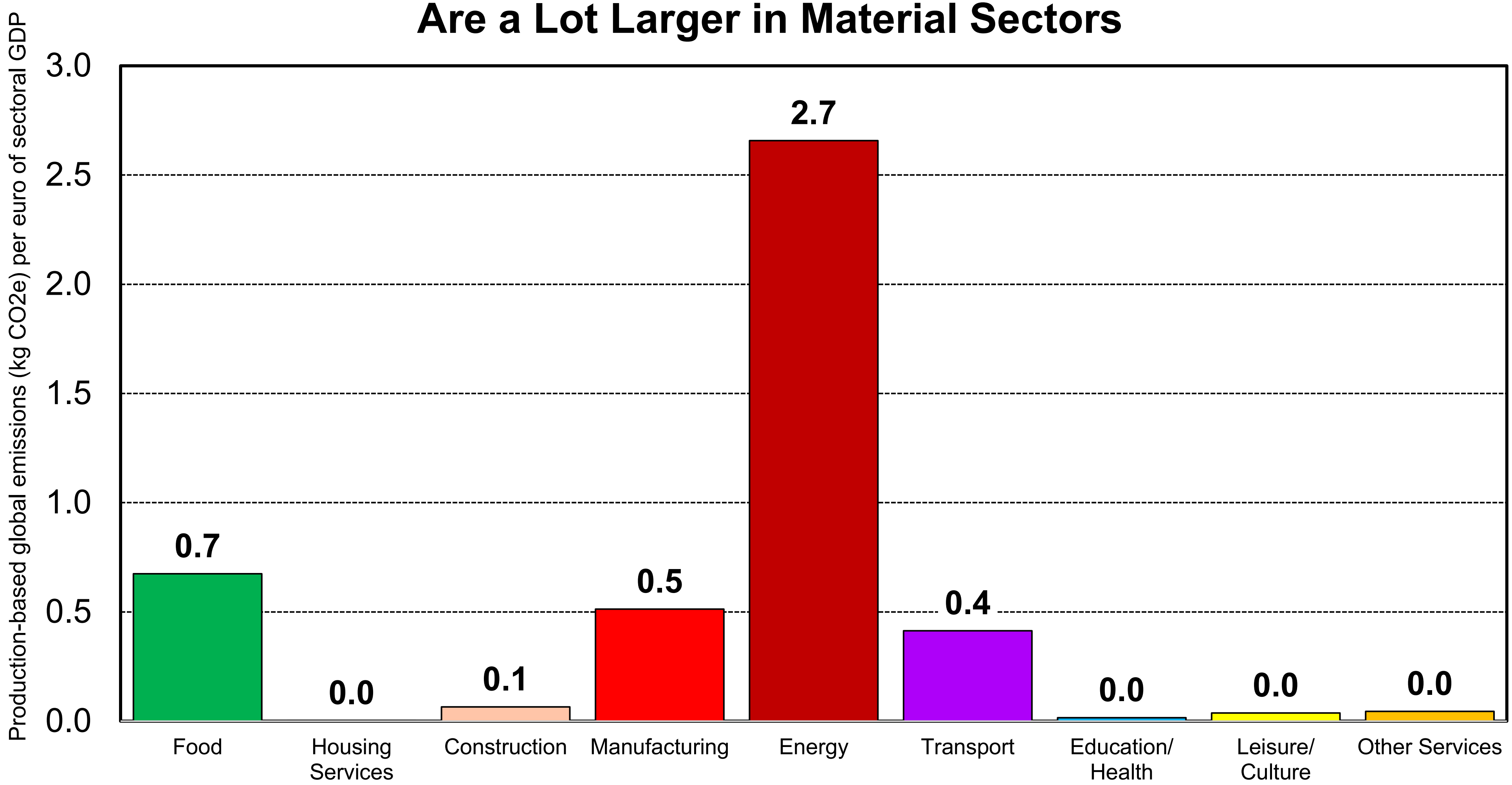
Interpretation. Out of the 57Gt of global GHG emissions in 2025, about 25 originate from the energy sector, 10 from manufacturing sector, 7 from the food sector and 6 from the household sector (direct energy use by households). This production-based perspective is partly artificial, however, as it ignores the intermediate inputs used by the various sectors. **Note**: Emissions of the household sector correspond to direct energy consumption by households, primarily for residential heating and personal vehicle use, and are counted separately. **Sources and series**: wseed.world (S1)

Fig. 3b. Expenditure-Based GHG Emissions Are More Balanced Across Sectors than Production-Based Emissions



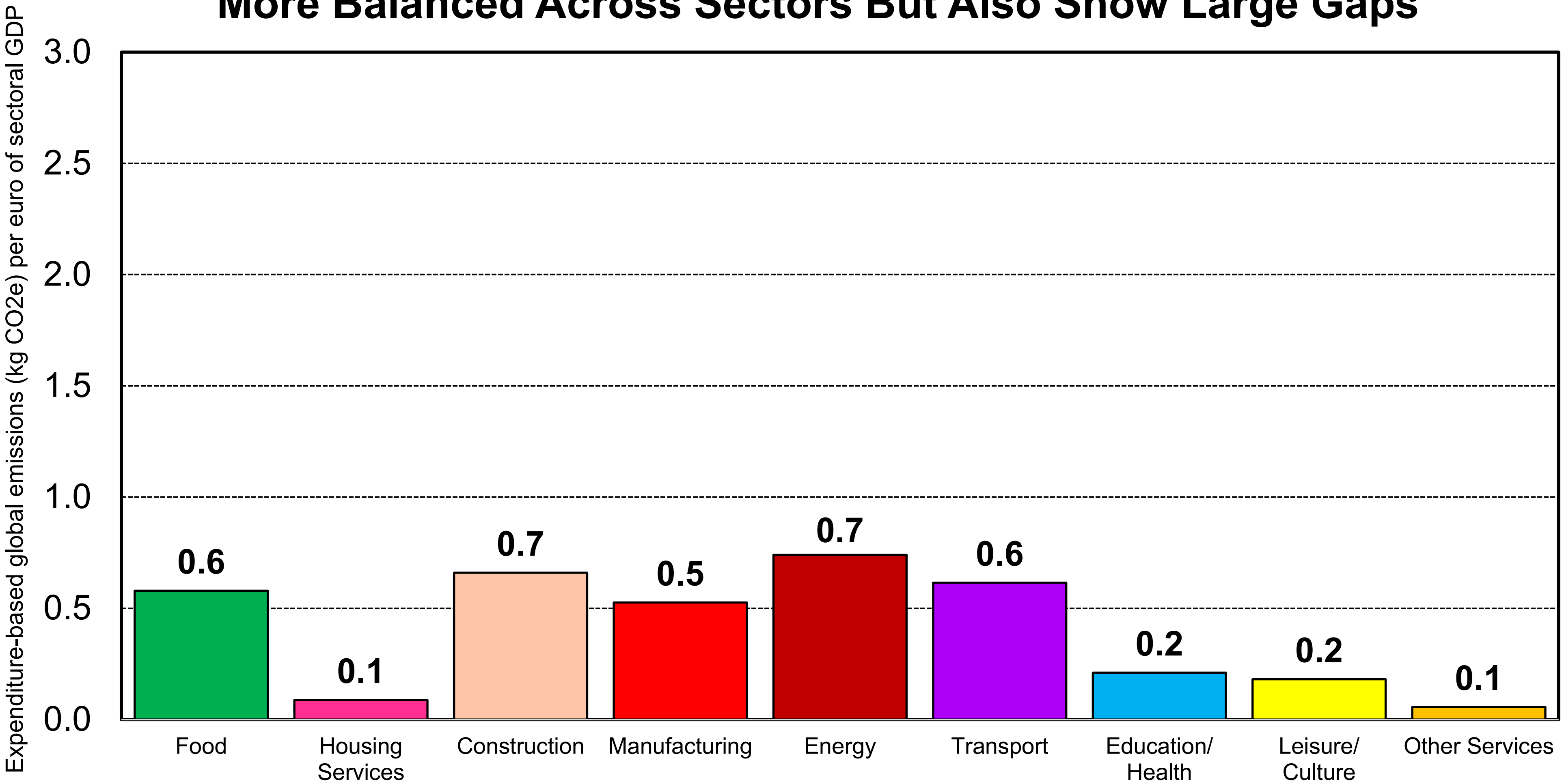
Interpretation. Once we take into account the global GHG emissions associated to the intermediate inputs used by the various sectors (expenditure-based emissions), then the distribution of emissions across sectors appears to be more balanced than under the perspective of production-based emissions. **Note**. Emissions of the household sector correspond to the direct energy consumption of households, primarily for residential heating and personal vehicle use, and are counted separately. **Sources and series**: wseed.world (S2)

Fig. 3c. Production-Based GHG Emission Intensities Are a Lot Larger in Material Sectors



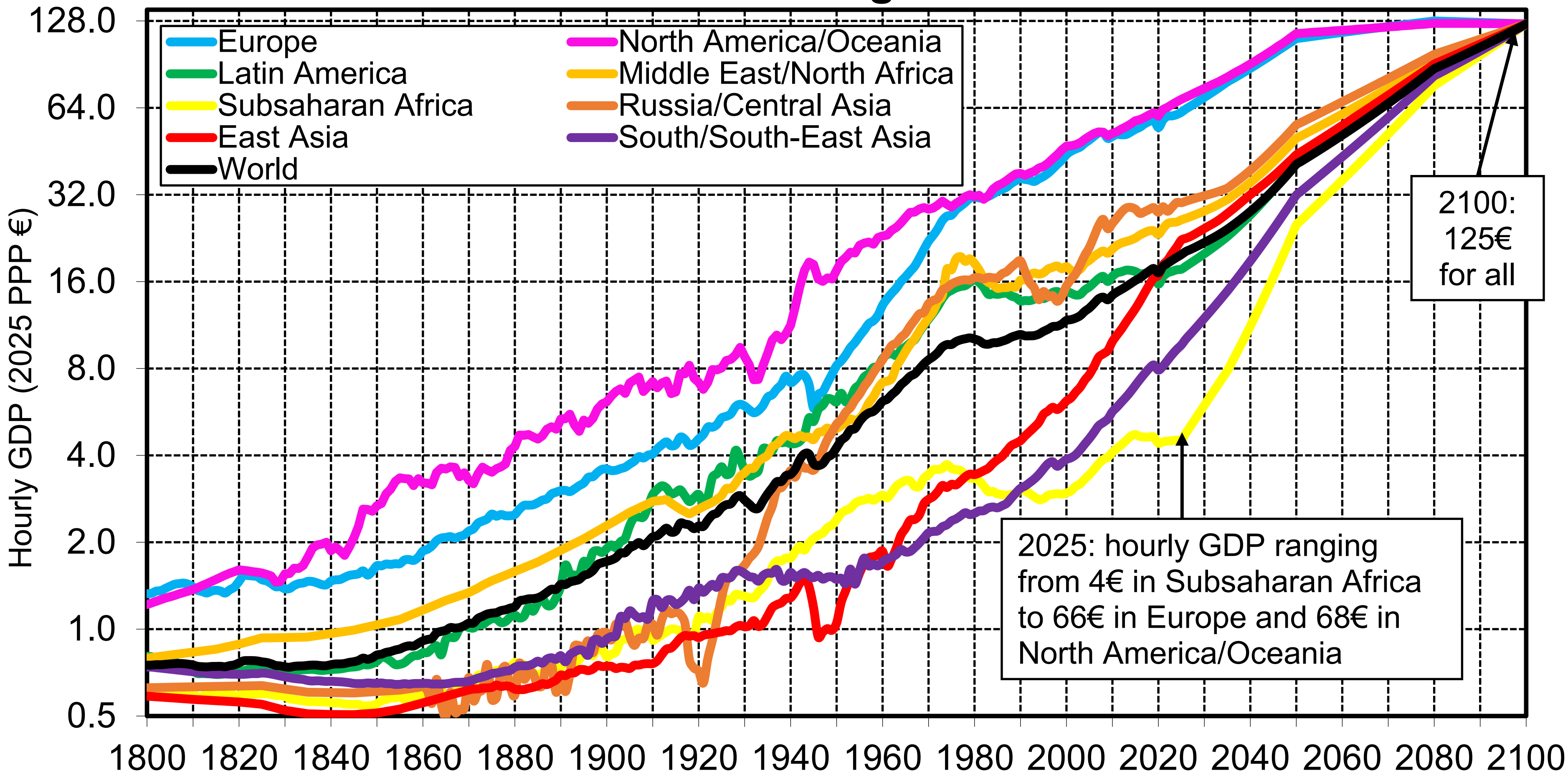
Interpretation. According to the production-based approach, global GHG emission intensities are a lot larger in material sectors and close to zero in immaterial sectors. This production-based perspective is partly artificial, however, as it ignores the intermediate inputs used by the various sectors. **Sources and series**: wseed.world (S3)

Fig. 3d. Expenditure-Based GHG Emission Intensities Are More Balanced Across Sectors But Also Show Large Gaps



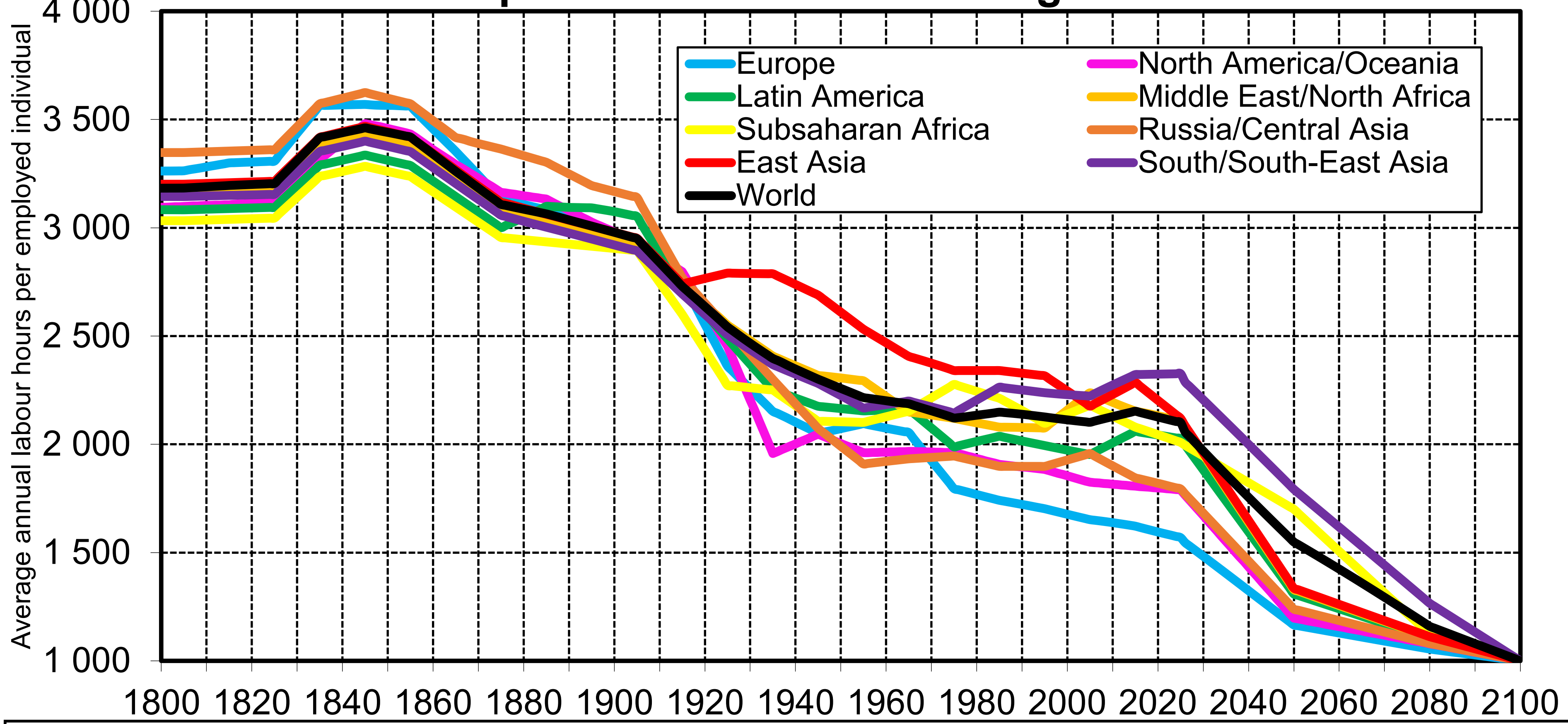
Interpretation. Because they take into account intermediate inputs, expenditure-based global GHG emissions intensities are more balanced across sectors than production-based intensities. But they also show large gaps: immaterial sectors have GHG intensities that are around three to four times smaller (per euro of sectoral GDP) than material sectors, which is already very substantial. **Sources and series**: wseed.world (S4)

Fig. 4. World Productivity Trends 2025-2100: Sustainable Convergence Scenario

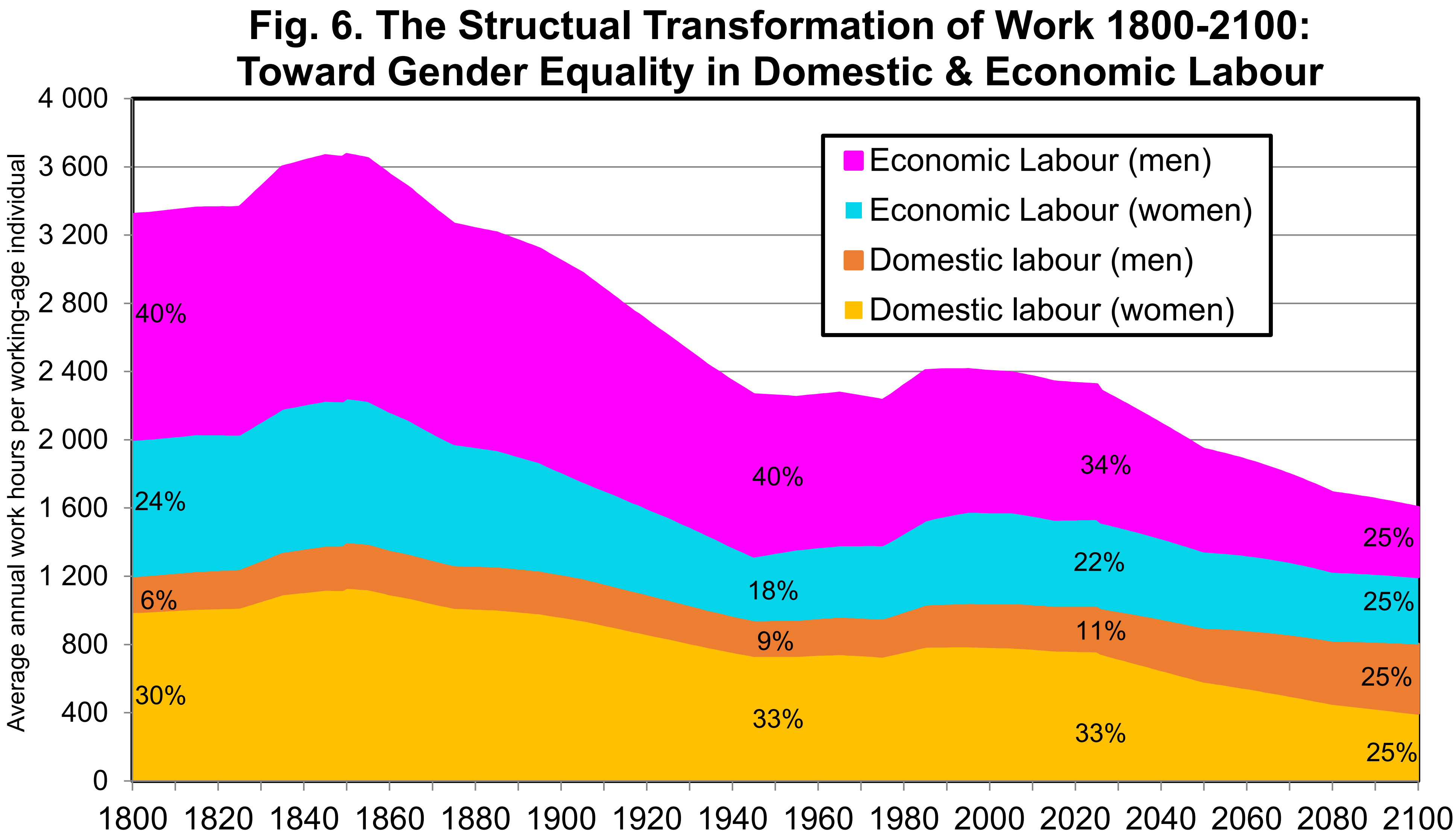


Interpretation. Under the Sustainable Convergence scenario, all countries converge toward high productivity by 2100, namely 125€ in hourly GDP (gross domestic product per economic labour hour). **Sources and series**: see wseed.world (F1a)

Fig. 5. Using Productivity Gains to Reduce Work Hours & Material Footprint: Sustainable Convergence 2025-2100



Interpretation. Under the Sustainable Convergence scenario, average annual labour hours decline from about 2100 to 1000 hours globally between 2025 and 2100. Note. Annual labour hours around 3000-3500 hours correspond to about 60-65 hours per week all year long. Annual hours around 2000 hours correspond to 40 hours per week during 50 weeks (2 weeks in paid vacation); annual hours around 1600 hours correspond to 35 hours per week during 47 weeks (5 weeks in paid vacation); annual hours around 1000 hours correspond to 25 hours per week during 40 weeks (12 weeks in paid vacation). **Sources and series**: wseed.world (E1a)



Interpretation. In the Sustainable Convergence scenario, working-age men and women are projected to supply the same quantity of economic labour and domestic labour and to receive equal average pay. This would represent a continuation of the trend toward gender equality observed between 1950 and 2025, albeit with a major acceleration. **Sources and series**: wseed.world (E1b)

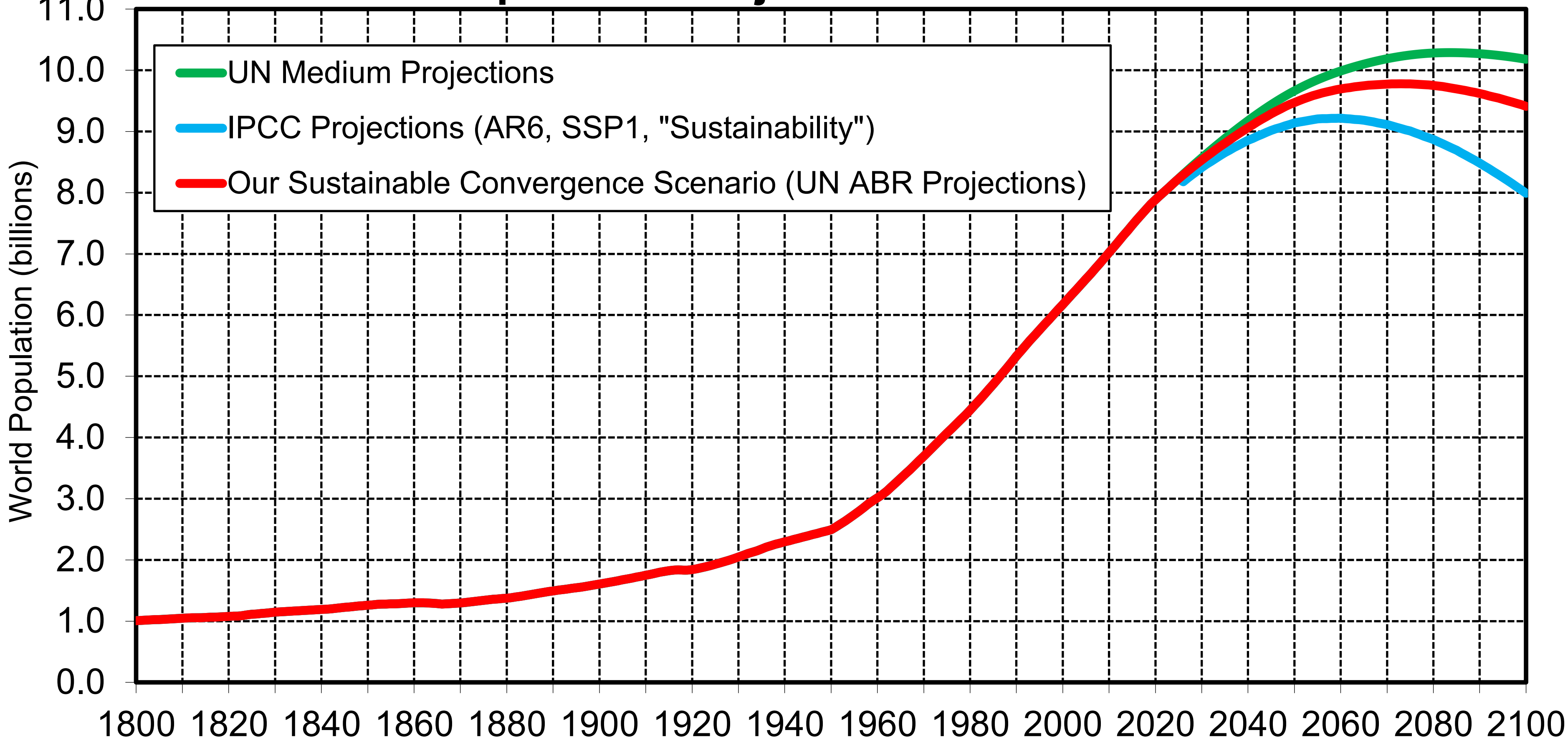
Table 10. Using Productivity Gains to Reduce Labour Hours: Lessons from the Past and Scenarios for the Future	
	Share of Productivity Gains Devoted to Extra Leisure (vs Extra Production)
1800-2025	**32%**
incl. 1800-1860	-4%
incl. 1860-1980	40%
incl. 1980-2025	-9%
2025-2100 (Sustainable Convergence Scenario)	**44%**

Interpretation. According to the "sustainable convergence" scenario, 44% of productivity gains will be devoted to extra leisure (as opposed to extra production) at the global level over the 2025-2100 period. This is roughly in line with the historical record observed during the 1860-1980 period (slightly more ambitious). **Source:** wseed.world (F2a)

Table 11. Hourly GDP Growth Rates, 1950-2100 : Sustainable Convergence Scenario									
Annual growth rates of hourly productivity (GDP per economic labour hour, 2025 PPP Euros)	**World**	**Europe**	**North America/ Oceania**	**Latin America**	**Middle East/North Africa**	**Subsaharan Africa**	**Russia/ Central Asia**	**East Asia**	**South & South-East Asia**
1950-1990	**2.3%**	**3.8%**	1.9%	2.0%	3.0%	0.6%	3.3%	3.7%	1.8%
1990-2025	**1.8%**	1.5%	1.7%	0.7%	1.4%	1.1%	1.3%	**4.7%**	3.3%
2025-2100 (Sustainable Convergence Scenario)	**2.5%**	0.9%	0.8%	2.6%	2.1%	**4.5%**	1.9%	2.3%	3.5%

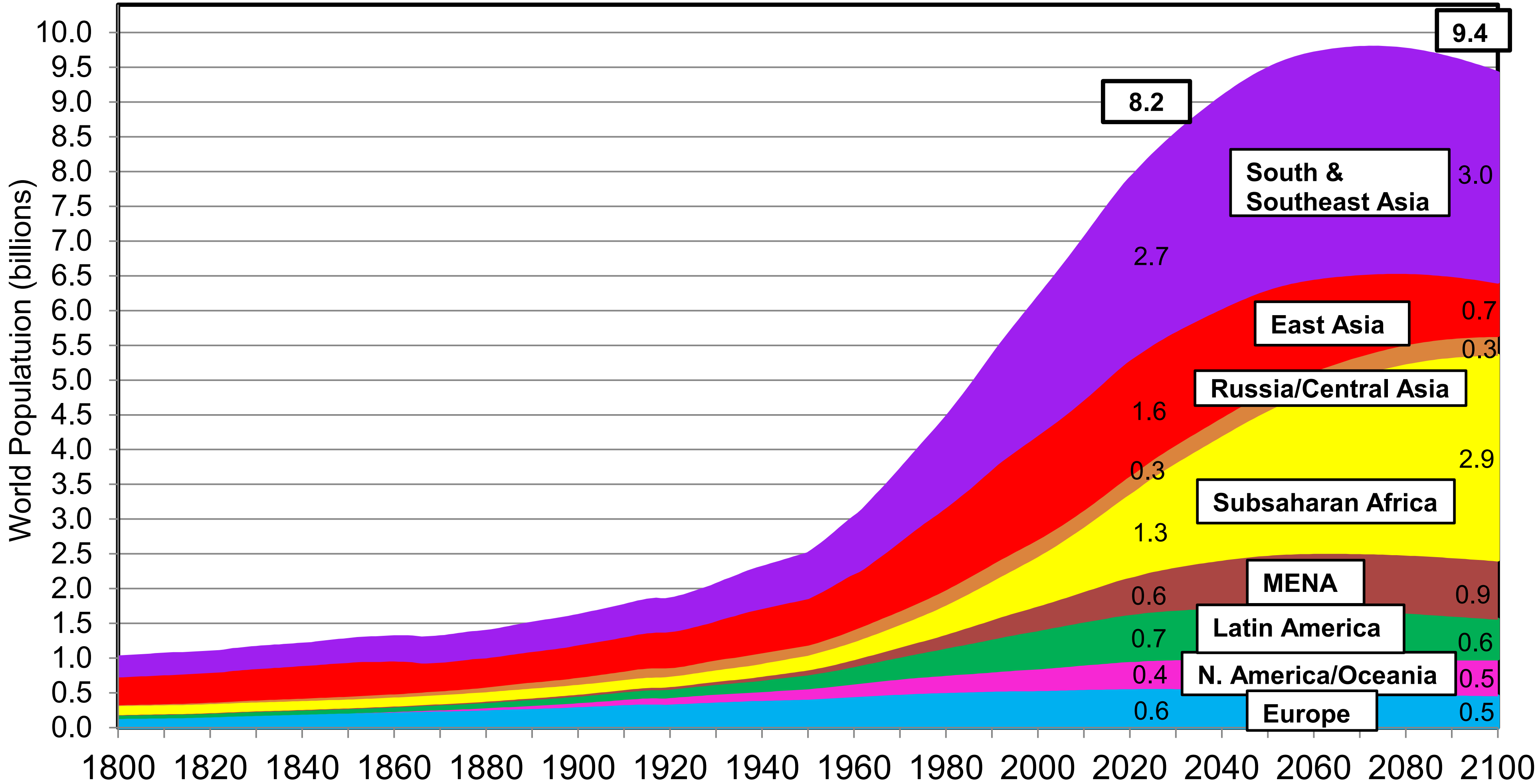
Interpretation. According to the "sustainable convergence" scenario, hourly GDP grows at higher speed in poor countries than in rich countries over the 2025-2100 period (especially in Subsaharan Africa, with a productivity growth rate comparable to that observed in Europe over 1950-1990 or in East Asia over 1990-2025), resulting into the same productivity levels in all countries by 2100. **Source:** wseed.world (F2b)

Fig. 7. Sustainable Convergence Scenario: Population Projections 2025-2100



Interpretation. According to our Sustainable Convergence scenario, world population rises from 8.2 billion in 2025 to 9.8 billion in 2070, before declining to 9.4 billion by 2100. This corresponds to UN ABR scenario (accelerated birth rate decline) and leads to smaller 2100 population than UN medium scenario (10.2 billion), thanks to economic convergence. IPCC AR6 SSP1 projections assume an even smaller 2100 population (8.0 billion) and appear to be more restrictive (population-wise) than the most restrictive UN projections. **Sources and series**: wseed.world (Z1a)

Fig. 8. Sustainable Convergence Scenario: The Geography of Population Growth 2025-2100

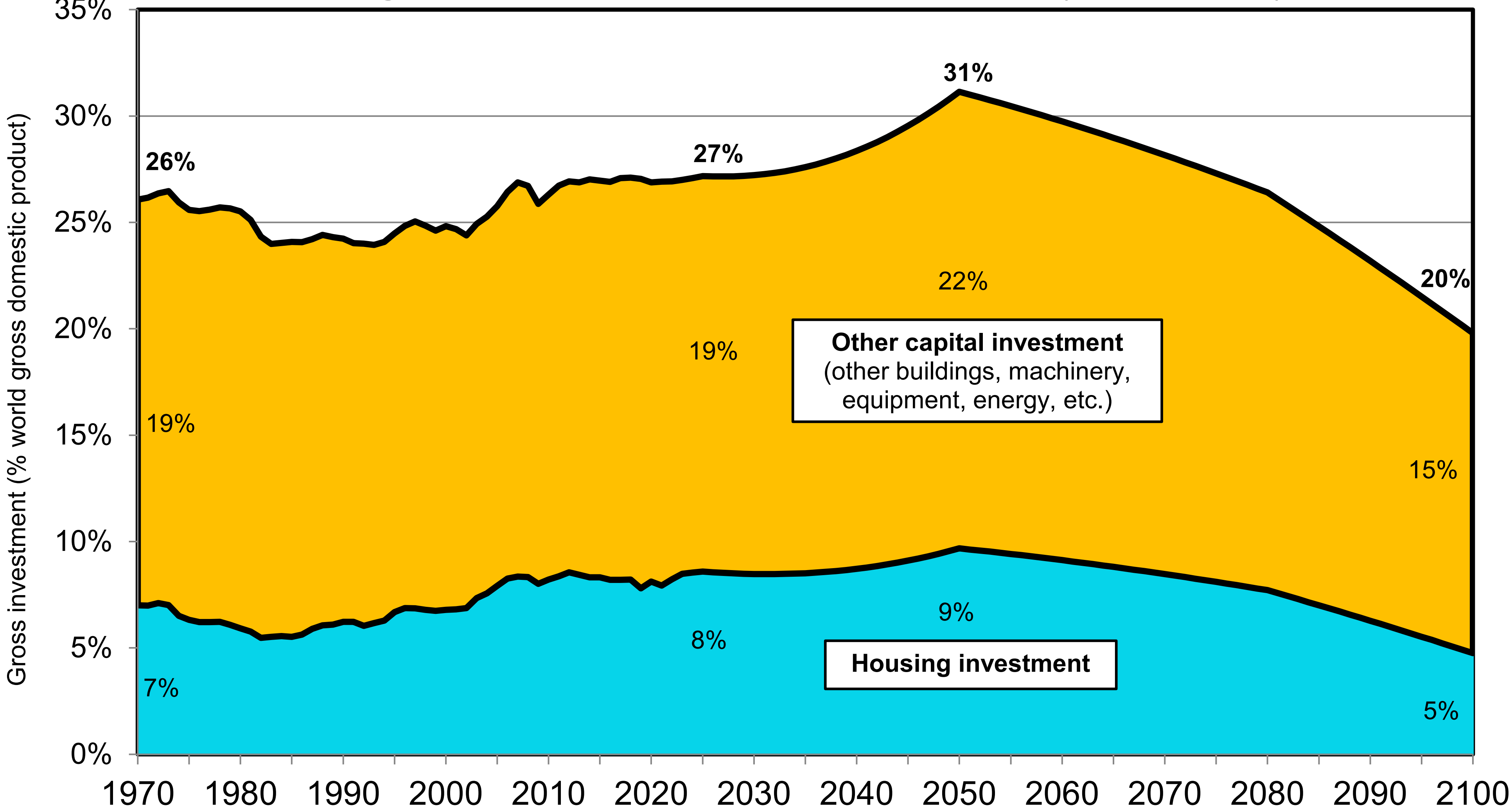


Interpretation. According to the Sustainable Convergence scenario (and to all existing population projections), population growth over the 2025-2100 period will come entirely from the world's poorest regions, namely Subsaharan Africa and to a lesser extent South & South-East Asia.
Sources and series: wseed.world (Z1b)

Table 12. The Changing Structure of World Growth, 1800-2100			
(annual growth rate)	**Population**	**Per Capita GDP**	**Total GDP**
1800-2025	**0.9%**	**1.3%**	**2.2%**
1800-1910	0.5%	0.7%	1.3%
1910-1950	0.9%	1.1%	2.0%
1950-1990	1.9%	2.4%	4.4%
1990-2025	1.2%	1.9%	3.1%
2025-2100	**0.2%**	**1.7%**	**1.9%**
2025-2050	0.6%	1.9%	2.5%
2050-2080	0.1%	1.8%	1.9%
2080-2100	-0.2%	1.2%	1.1%

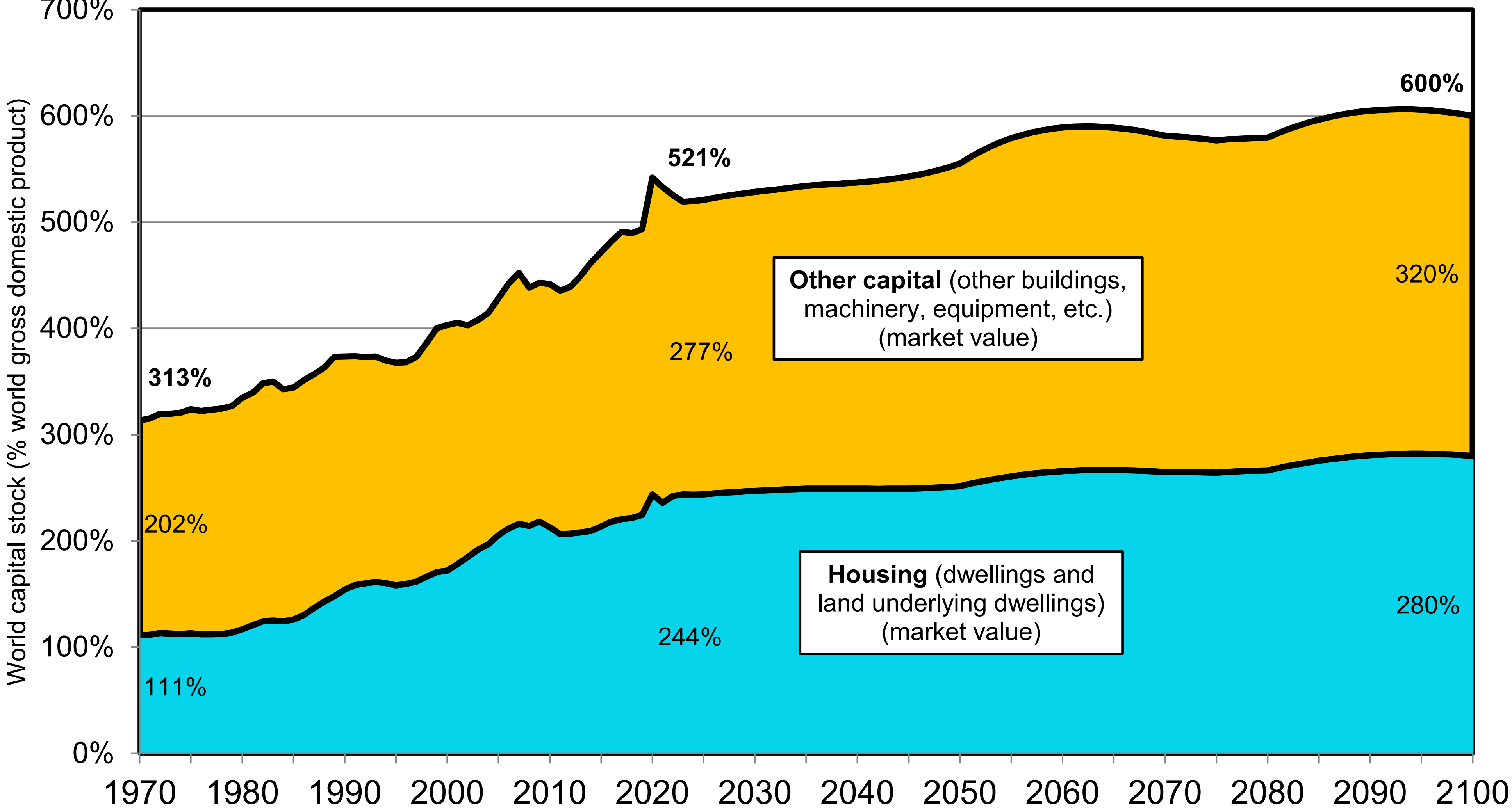
Interpretation. At the world level, population has been rising at 0.9% per year on average between 1800 and 2025, while per capita GDP rose at a rate of 1.3%, resulting into an total growth rate of 2.2% for aggregate GDP. By the end of he 21st century, most or all of the growth will come from per capita GDP. **Source:** wseed.world (Z1b)

Fig. 9. Gross Investment, 1970-2100 (% world GDP)



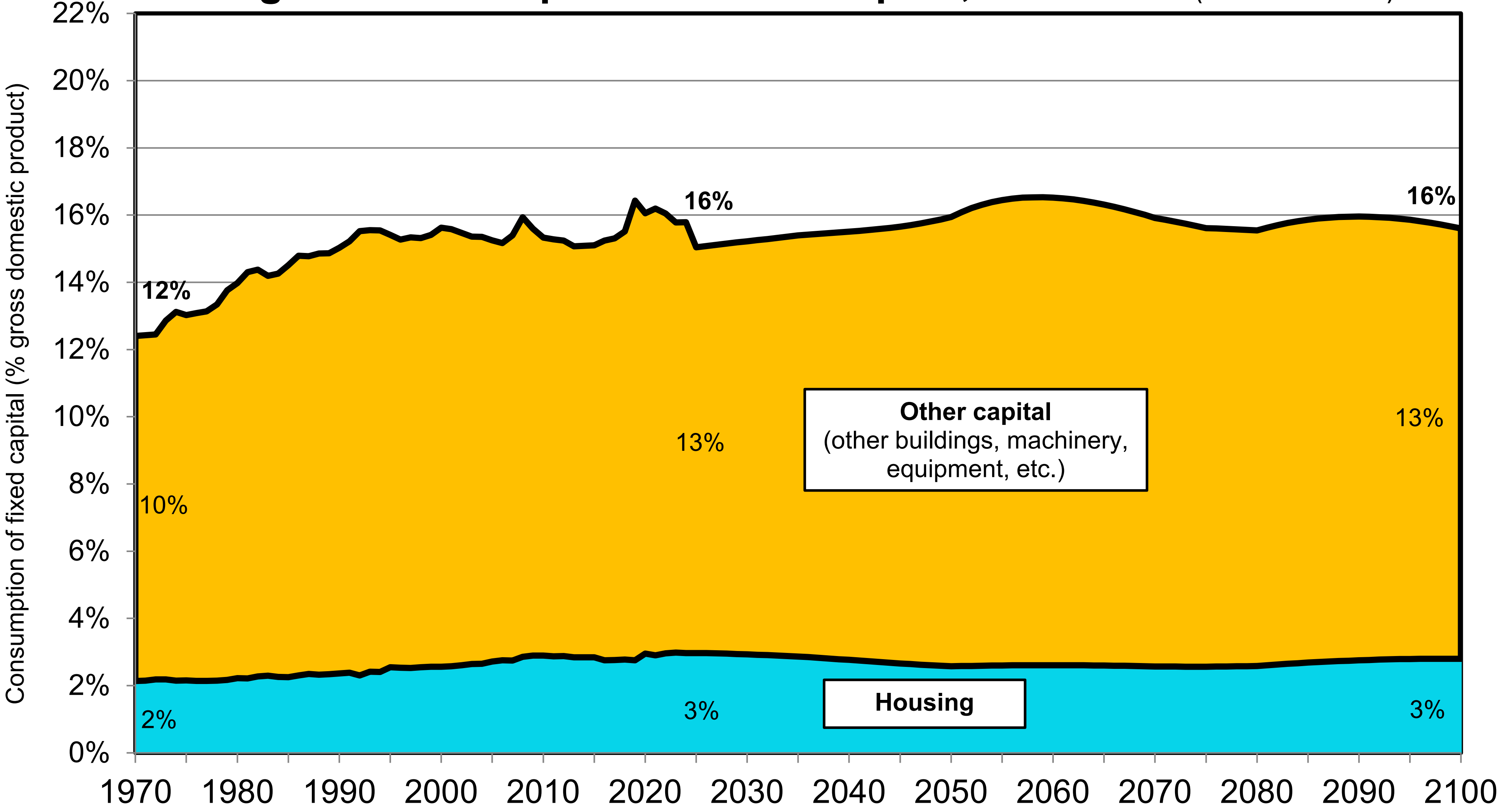
Interpretation. At the world level, gross investment rose from 26% of GDP in 1970 (including 7% for housing investment and 19% for other capital investment) to 27% in 2025 (including 8% for housing and 19% for other capital). In our benchmark scenario, it is projected to rise to 31% by 2050 (largely due to the scheduled rise of climate/energy investment) and then to decline to about 20% by 2100 (largely due to the plumetting of population growth). **Sources and series**: wseed.world (J0a)

Fig. 10. The World Capital Stock, 1970-2100 (% world GDP)



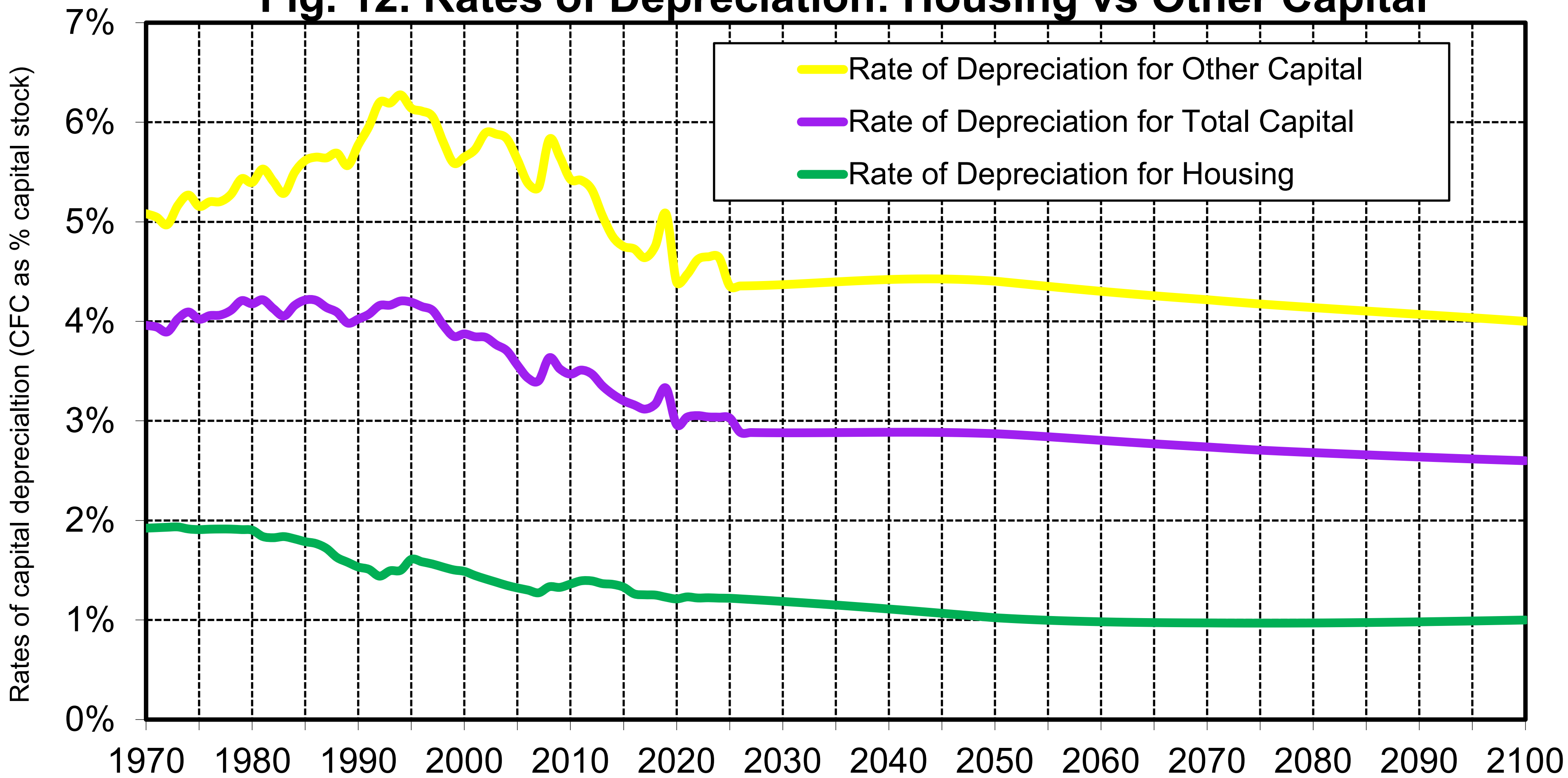
Interpretation. At the world level, the total capital stock increased from 313% to 521% of gross domestic product between 1970 and 2025 and is projected to rise to 600% by 2100. The observed rise between 1970 and 2025 and the projected rise between 2025 and 2100 are due both to the rise of housing and other capital (other buildings, machinery, equipment, energy infrastructures, etc.). **Sources and series**: wseed.world (Jk1)

Fig. 11. Consumption of Fixed Capital, 1970-2100 (% world GDP)



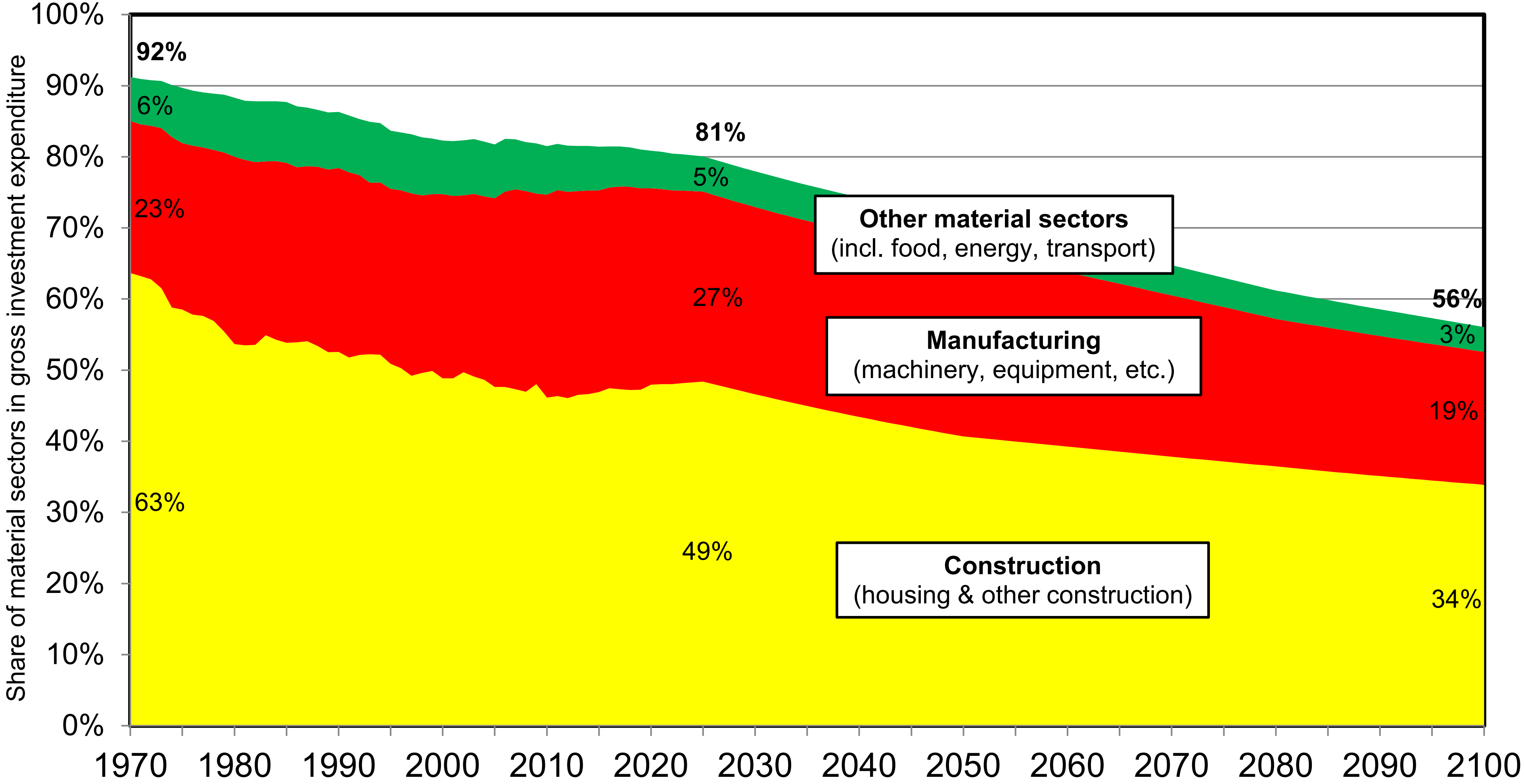
Interpretation. At the world level, consumption of fixed capital (capital depreciation) rose from about 12% of GDP in 1970 to 16% in 2025. It is scheduled to stabilize around 16% of GDP over the 2025-2100 period. Observed series 1970-2025. **Sources and series**: wseed.world (J0b)

Fig. 12. Rates of Depreciation: Housing vs Other Capital



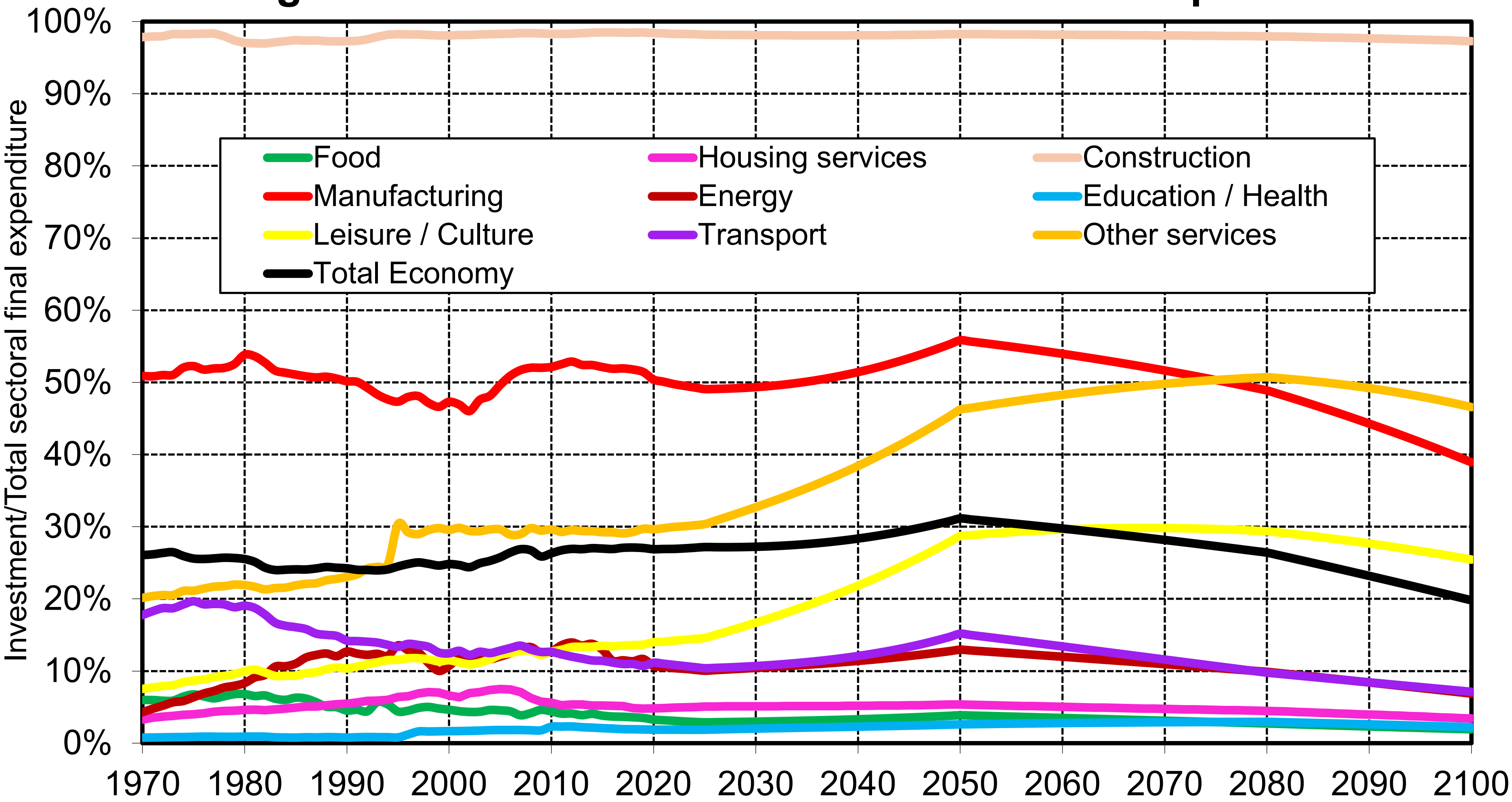
Interpretation. At the world level, the rate of capital depreciation (i.e. consumption of fixed capital as a fraction of capital stock) declined from 4.0% in 1970 to 3.0% in 2025 and is projected to further decrease to 2.6% by 2100. Depreciation rates for housing have always been smaller than for other capital, reflecting higher obsolescence of other capital (other buildings, machinery, equipment, etc.). Falling depreciation rates reflect various factors, including rising asset values, especially over the 1990-2025 period. I.e. consumption of fixed capital did rise as a fraction of GDP (from 12% to 16% between 1970 and 2025), but less so than the total market value of capital stock. **Sources and series**: wseed.world (J0c)

Fig. 13. Sustainable Convergence Scenario: Reduced Share of Material Sectors in Investment



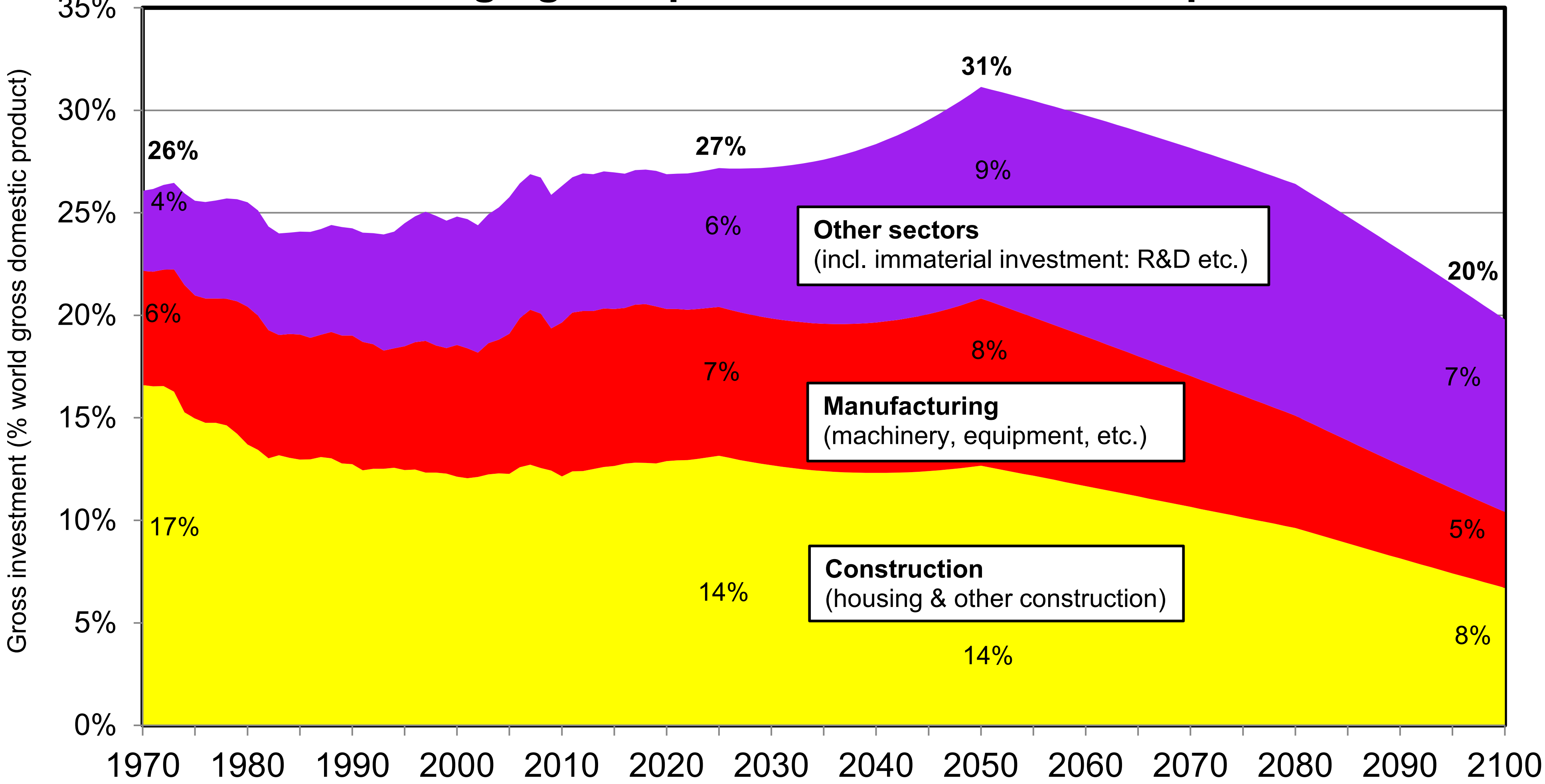
Interpretation. The share of material sectors in final consumption expenditure rose from 92% to 81% at the world level between 1970 and 2025. It is a projected to decline to 56% by 2100 according to our Sustainable Convergence scenario. This corresponds to a 30% reduction in the share of material sectors in investment expenditure. **Sources and series**: wseed.world (J0m)

Fig. 14. Investment Share in Gross National Expenditure



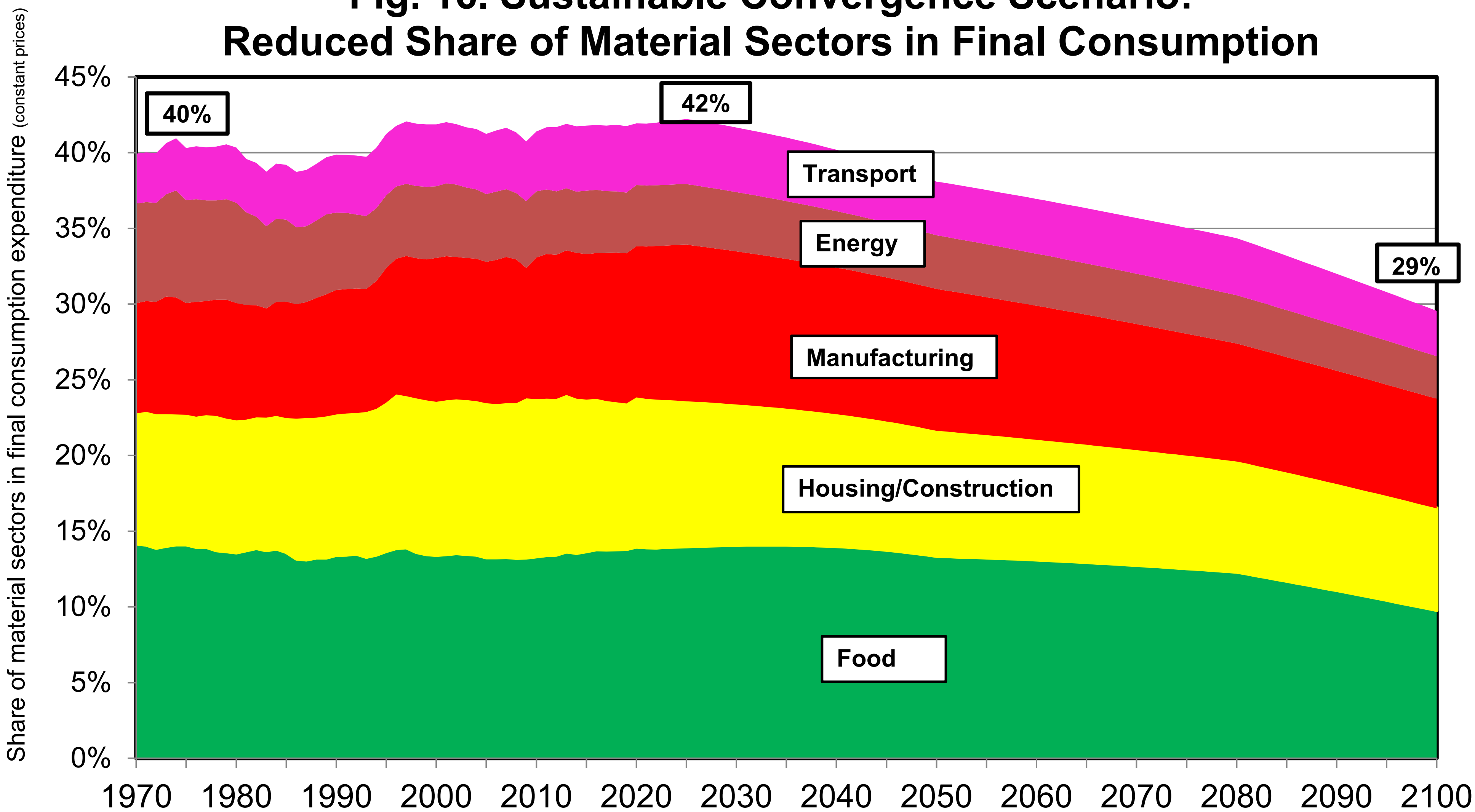
Interpretation. The share of investment in gross national expenditure (final consumption + investment) has always been around 95-100% in construction, 50% in manufacturing and less than 10% in most other sectors, with the exception of other services, where the investment share rose from 20% to 30% between 1970 and 2025 and is projected to reach 47% by 2100. **Sources and series**: wseed.world (J0n)

Fig. 15. Sustainable Convergence Scenario: The Changing Composition of Investment Expenditure



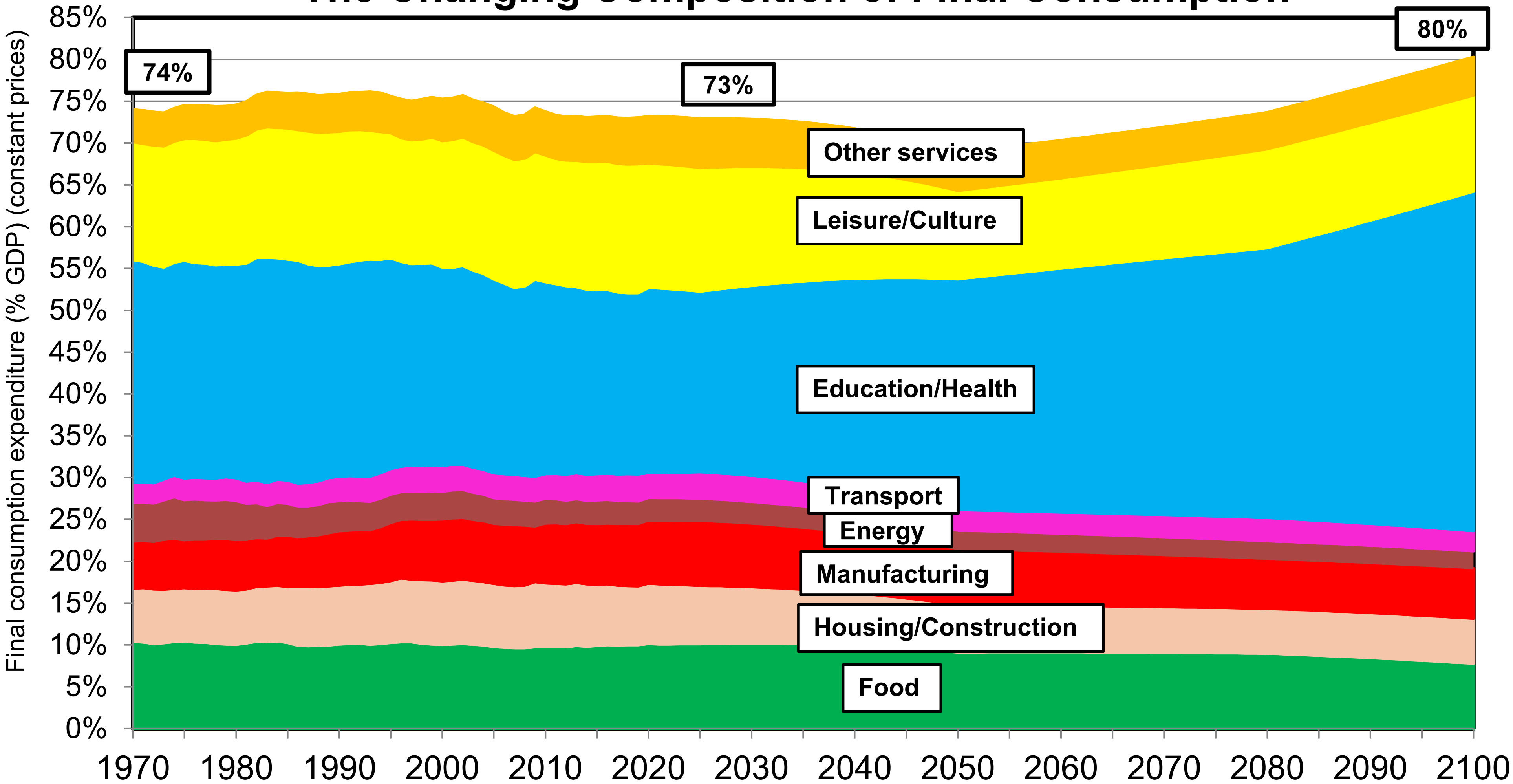
Interpretation. At the world level, gross investment rose from 26% of gross domestic product in 1970 to 27% in 2025. In our benchmark scenario, it is scheduled to rise until 2050-2060 and then to decline to about 20% by 2100, with a rising fraction of investment expenditure originating from sectors other than construction and manufacturing. **Sources and series**: wseed.world (J0o)

Fig. 16. Sustainable Convergence Scenario: Reduced Share of Material Sectors in Final Consumption



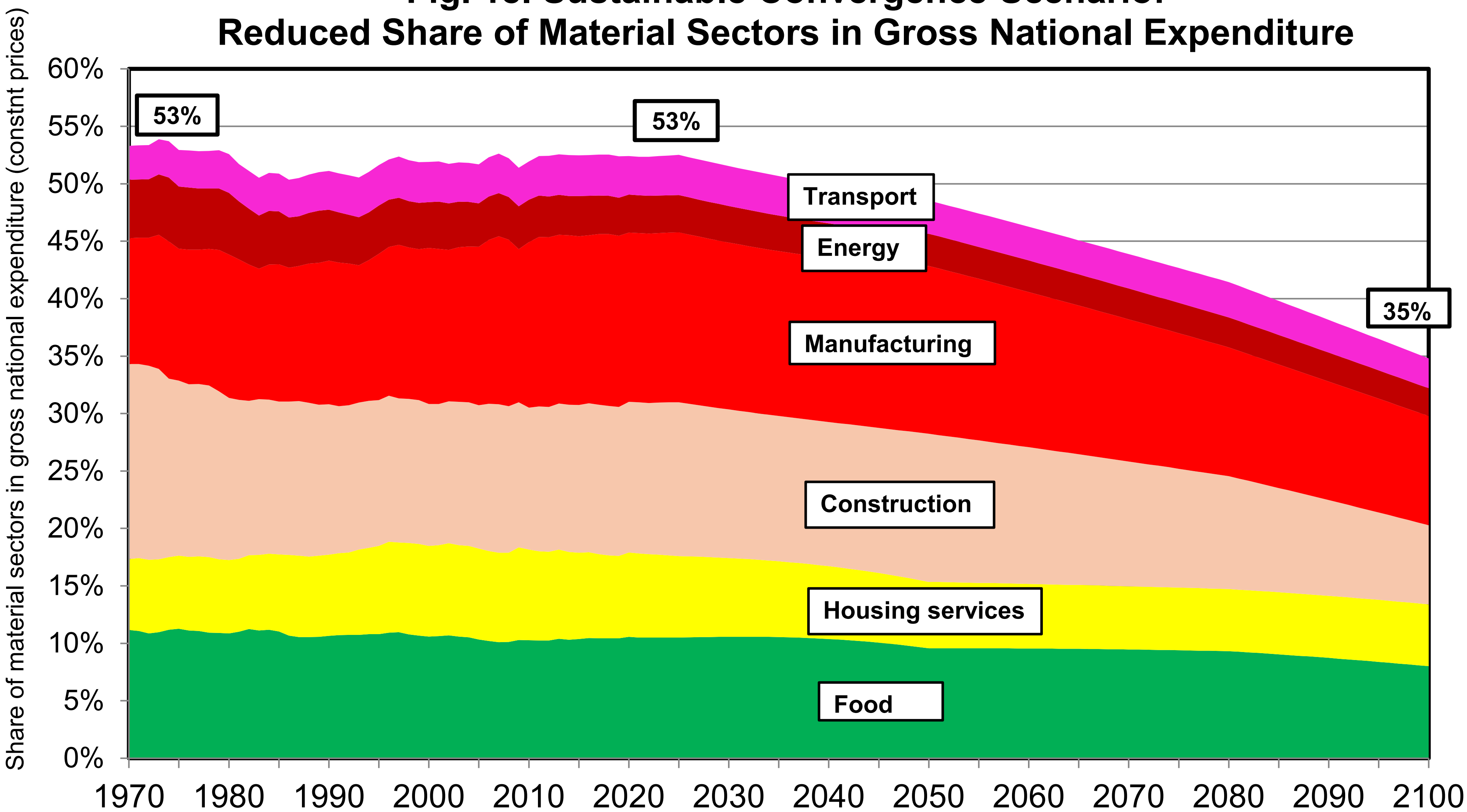
Interpretation. The share of material sectors in final consumption expenditure rose from 40% to 42% at the world level between 1970 and 2025. It is a projected to decline to 29% by 2100 according to our Sustainable Convergence scenario. This corresponds to a 30% reduction in the share of material sectors in final consumption expenditure. **Sources and series**: wseed.world (I0m)

Fig. 17. Sustainable Convergence Scenario: The Changing Composition of Final Consumption



Interpretation. The share of immmaterial sectors (particularly education/health) in final consumption expenditure is scheduled to rise between 2025 and 2100 according to our Sustainable Convergence scenario. Aggregate final consumption is also scheduled to rise from 73% to 80% of GDP at the world level, as gross investment declines from 27% to 20%. **Sources and series**: wseed.world (I0r)

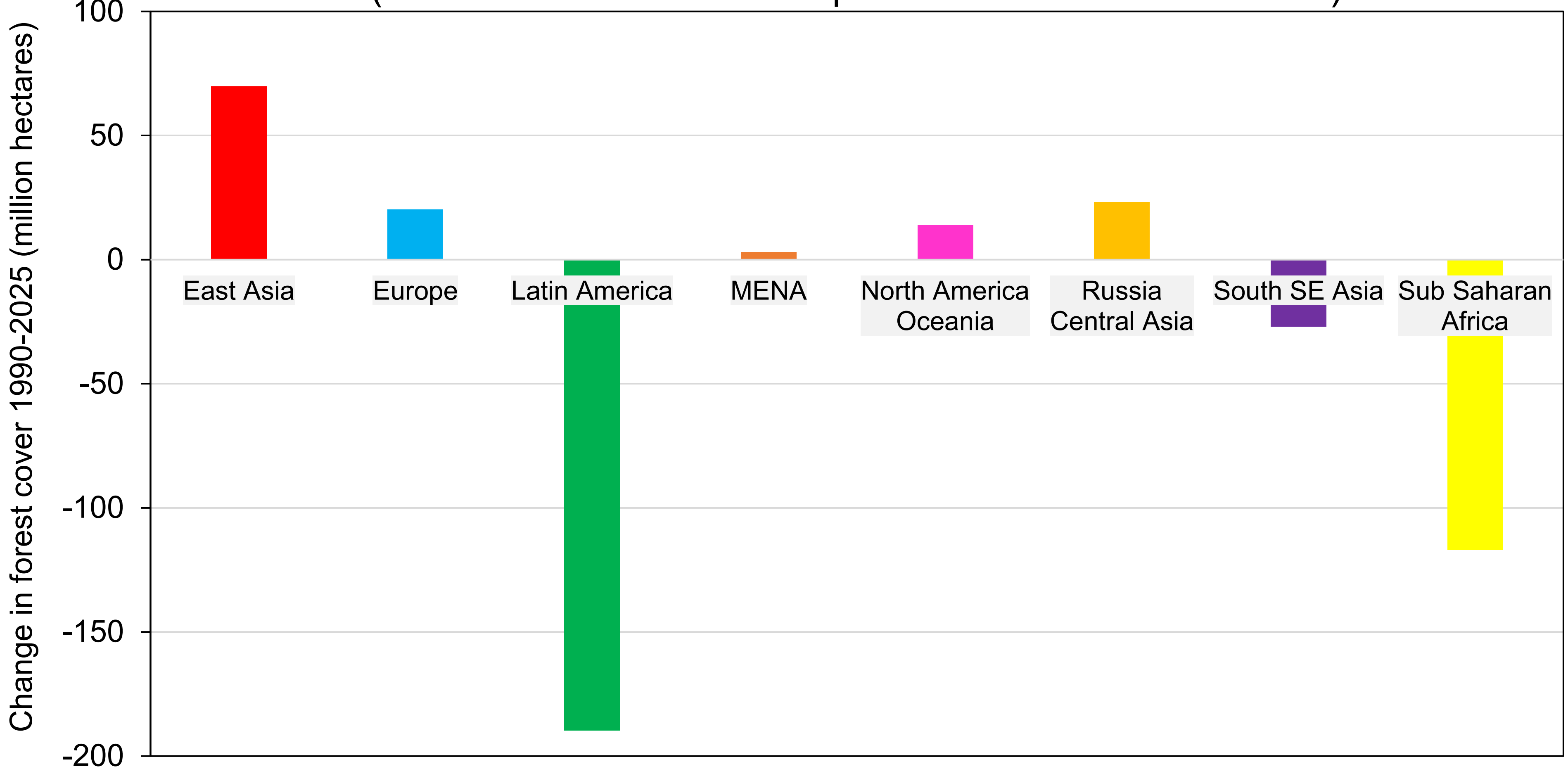
Fig. 18. Sustainable Convergence Scenario: Reduced Share of Material Sectors in Gross National Expenditure



Interpretation. The share of material sectors in gross national expenditure (final consumption and investment) remained stable at 53% at the world level between 1970 and 2025. It is a projected to decline to 35% by 2100 according to our Sustainable Convergence scenario. This corresponds to a 30% reduction in the share of material sectors in consumption and investment expenditure. **Sources and series**: wseed.world (G0m)

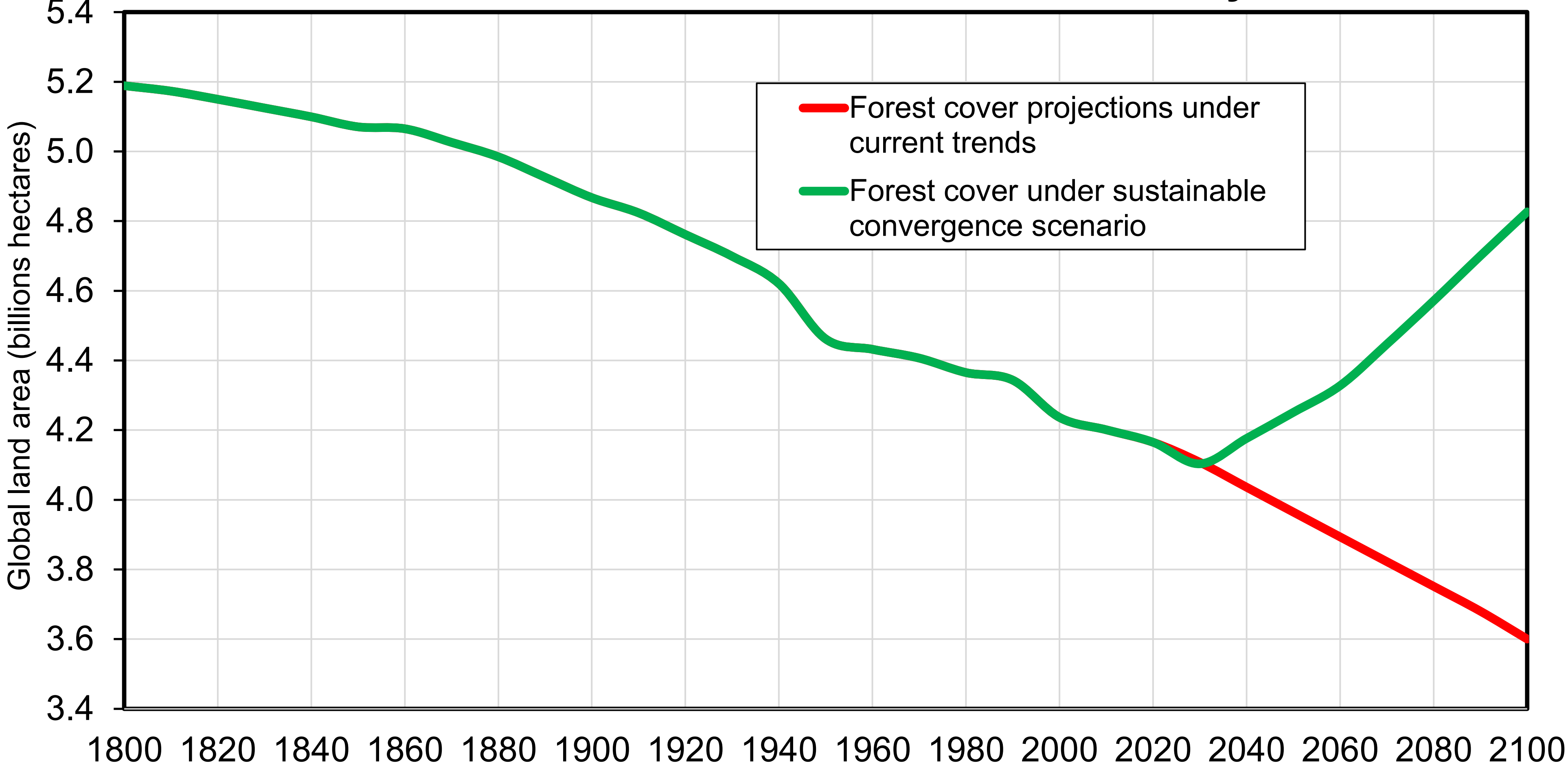
Fig. 19. Change in forest cover across world regions 1990-2025

(Global evolution over the period: -203 million hectares)



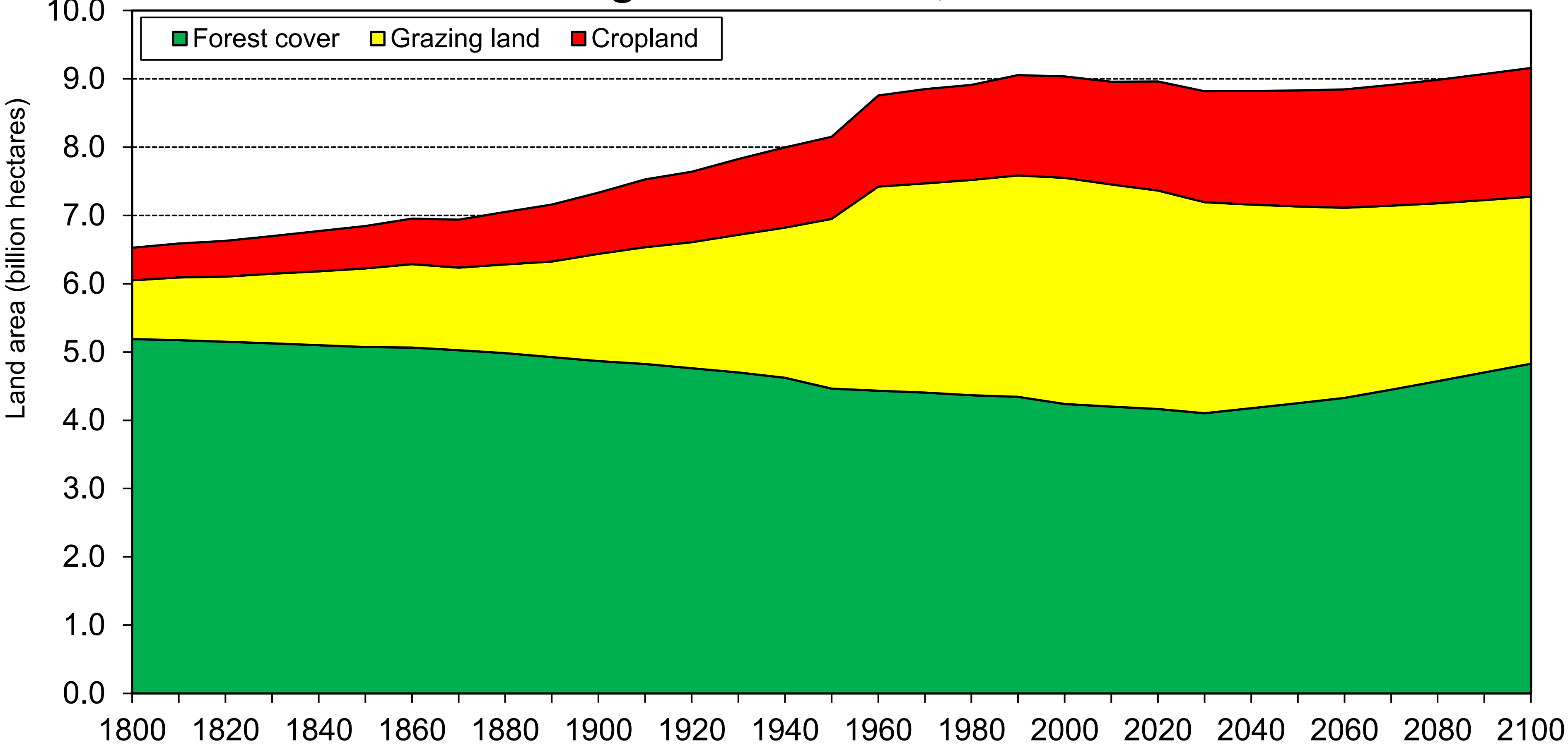
Interpretation. Global forest area declined by 203 millions hectares between 1990 and 2025 (in line with the long run decline of about 1.1 billion hectares observed between 1800 and 2025). This continued global forest decline results from large deforestation in the global South (Latin America, Subsaharan Africa, South & South-East Asia) and small reforestation in the global North (East Asia, Europe, North America, Russia). In addition, the areas which are currently under deforestation include denser forests with much stronger CO_2 absorption capacities per hectare (two to three times larger) than the areas under reforestation. **Sources and series**: wseed.world (U2)

Fig. 20. Sustainable Convergence: Deforestation Ban in 2030 & Gradual Return of Forest Cover to 1900 Level by 2100



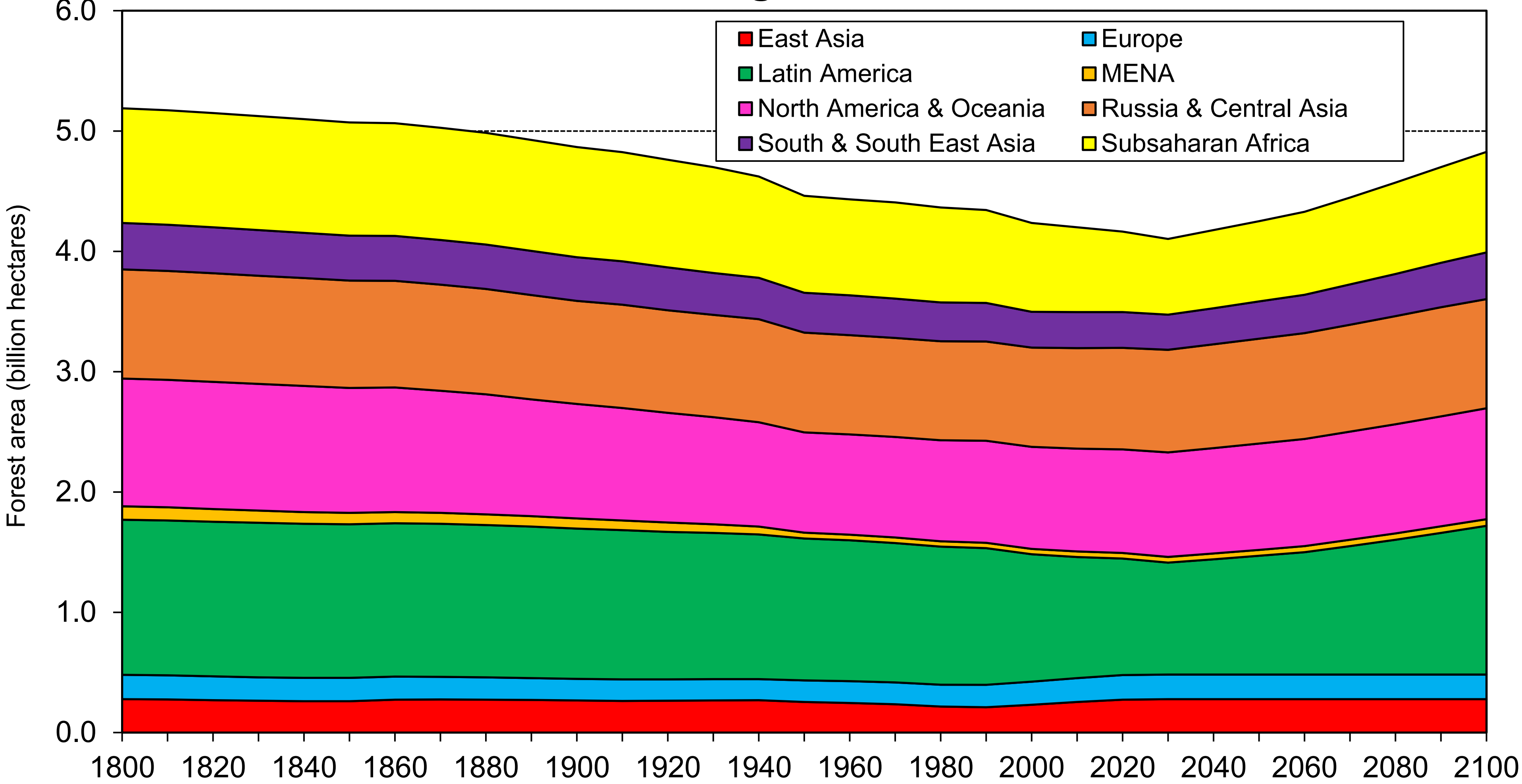
Interpretation. According to our Sustainable Convergence scenario, a complete ban on deforestation will be imposed in 2030 and a large reforestation plan will allow global forest cover to gradually rise from about 4.1 billion hectares in 2025 to 4.8 billion by 2100, i.e. approximately the same level as in 1900. In contrast, in the Productivist Convergence and Persistent Inequality scenarios, deforestation is expected to continue at the same speed as in recent decades, so that global forest cover will reach about 3.6 billion by 2100. **Sources and series**: wseed.world (U3)

Fig. 21. Global Agricultural Land (Grazing Land and Cropland) and Forest Cover under the Sustainable Convergence Scenario, 1800-2100



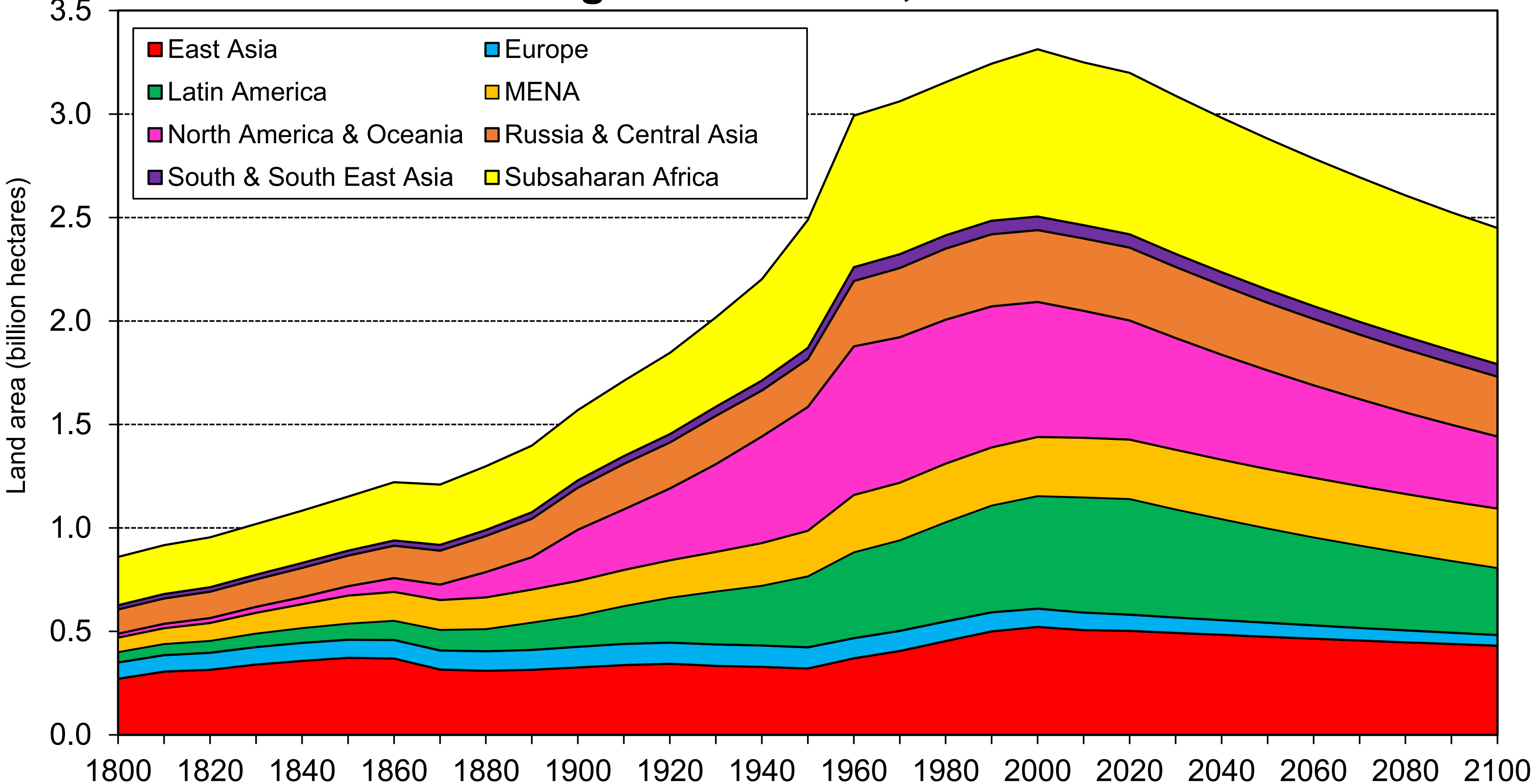
Interpretation. According to our Sustainable Convergence scenario, global forest cover rises from 4.1 billions hectares in 2025 to 4.8 billions by 2100 (i.e. approximately the same level as in 1900), while grazing land declines sharply from 3.2 to 2.4 billions and cropland rises moderately from 1.6 to 1.9 billions (in order to make up for the shift from meat to vegetables). **Sources and series**: wseed.world (U4)

Fig. 22a. Forest Cover by World Region Under Sustainable Convergence Scenario, 1800-2100



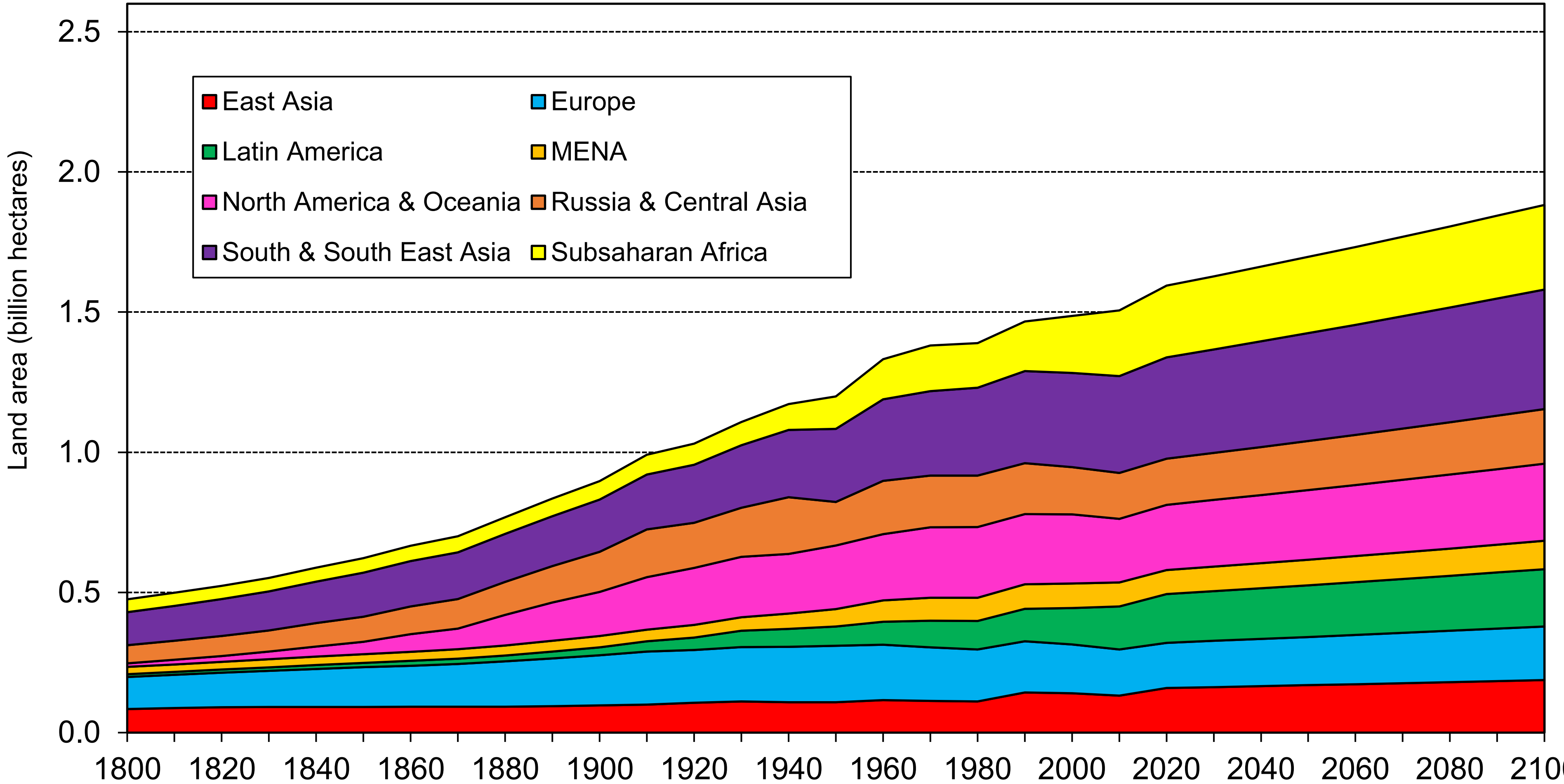
Interpretation. According to our Sustainable Convergence scenario, global forest cover rises from 4.1 billions hectares in 2025 to 4.8 billions by 2100 (i.e. approximately the same level as in 1900), with large increases in all regions. **Sources and series**: wseed.world (U5a)

Fig. 22b. Grazing Land by Region Under Sustainable Convergence Scenario, 1800-2100



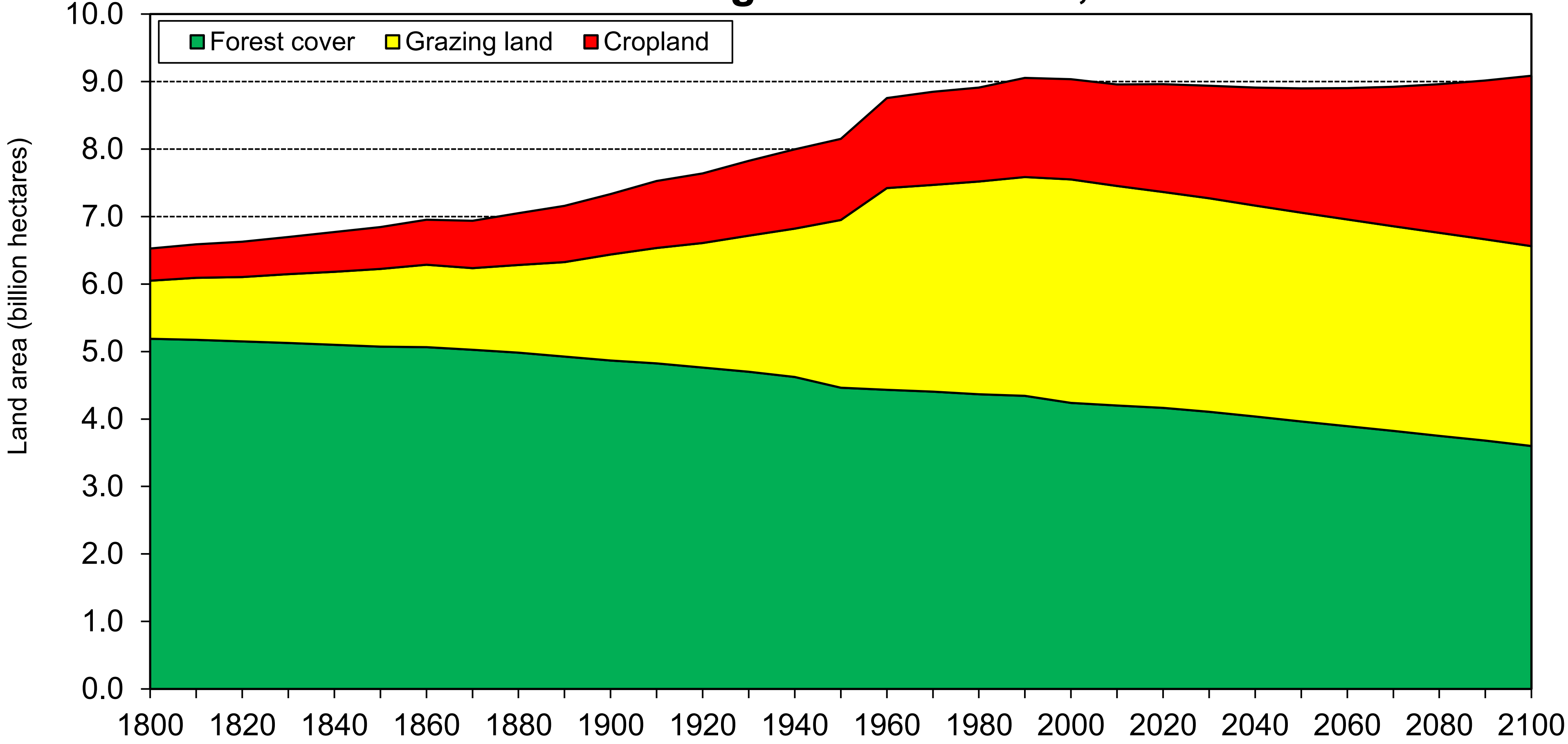
Interpretation. According to our Sustainable Convergence scenario, grazing land declines from 3.2 to 2.4 billions hectares between 2025 and 2100, with large declines in all regions. **Sources and series**: wseed.world (U5b)

Fig. 22c. Cropland by Region Under Sustainable Convergence Scenario, 1800-2100



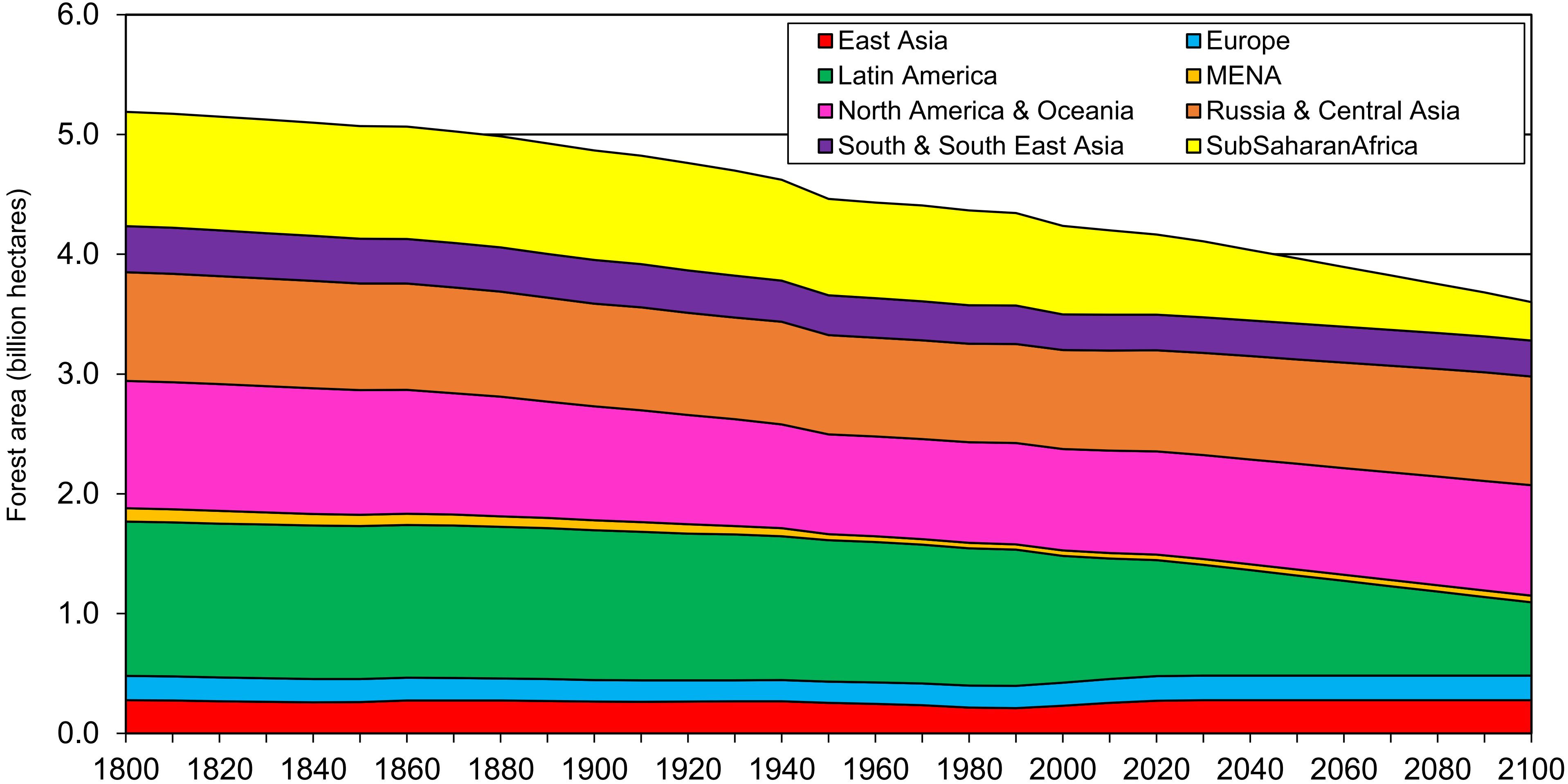
Interpretation. According to our Sustainable Convergence scenario, cropland rises moderately from 1.6 to 1.9 billions between 2025 and 2100 (in order to make up for the shift from meat to vegetables), with moderate increases in all regions. **Sources and series**: wseed.world (U5c)

Fig. 23. Global Agricultural Land (Grazing Land and Cropland) and Forest Cover under Persistant Inequality and Productivist Convergence Scenarios, 1800-2100



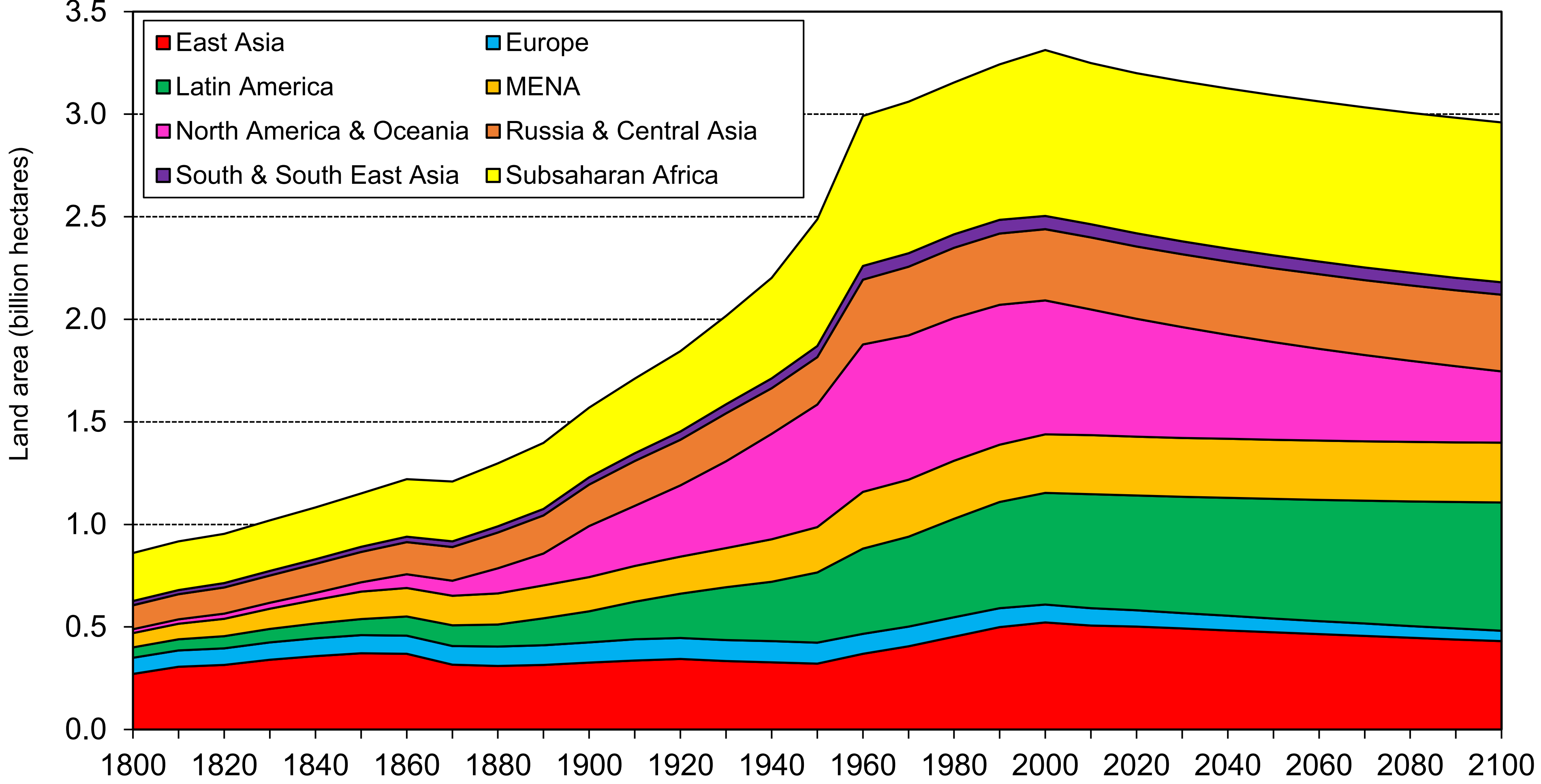
Interpretation. According to the Productivist Convergence and Persistent Inequality scenarios, global forest cover declines from 4.1 billions hectares in 2025 to 3.6 billions by 2100, while grazing land declines slightly from 3.2 to 3.0 billions and cropland rises from 1.6 to 2.5 billions.
Sources and series: wseed.world (U6)

Fig. 24a. Forest Cover by World Region Under Persistent Inequality and Productivist Convergence Scenarios



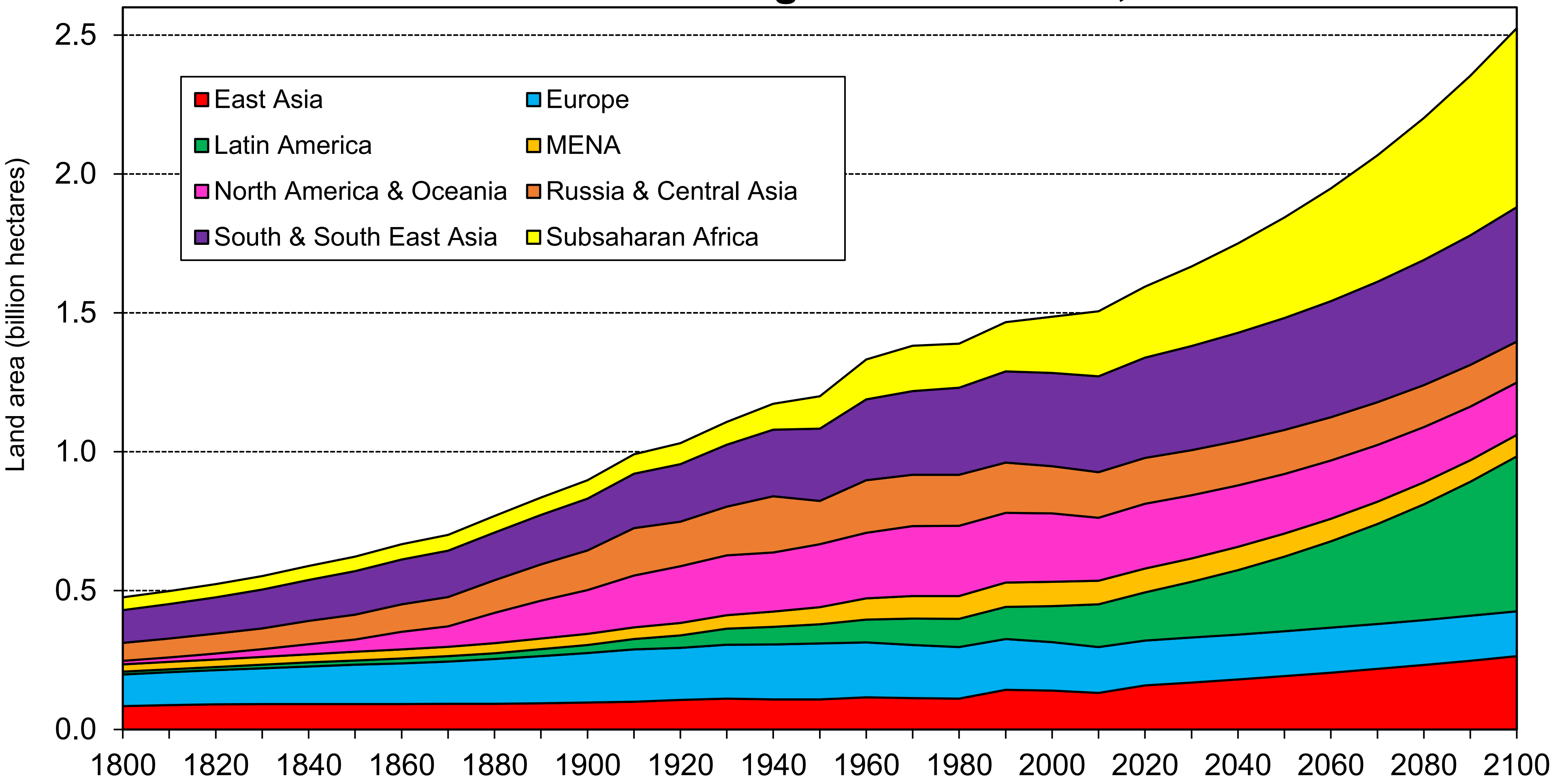
Interpretation. According to the Productivist Convergence and Persistent Inequality scenarios, global forest cover declines from 4.1 billions hectares in 2025 to 3.6 billions by 2100, with large declines in most regions. **Sources and series**: wseed.world (U7a)

Fig. 24b. Grazing Land by Region Under Persistent Inequality and Productivist Convergence Scenarios



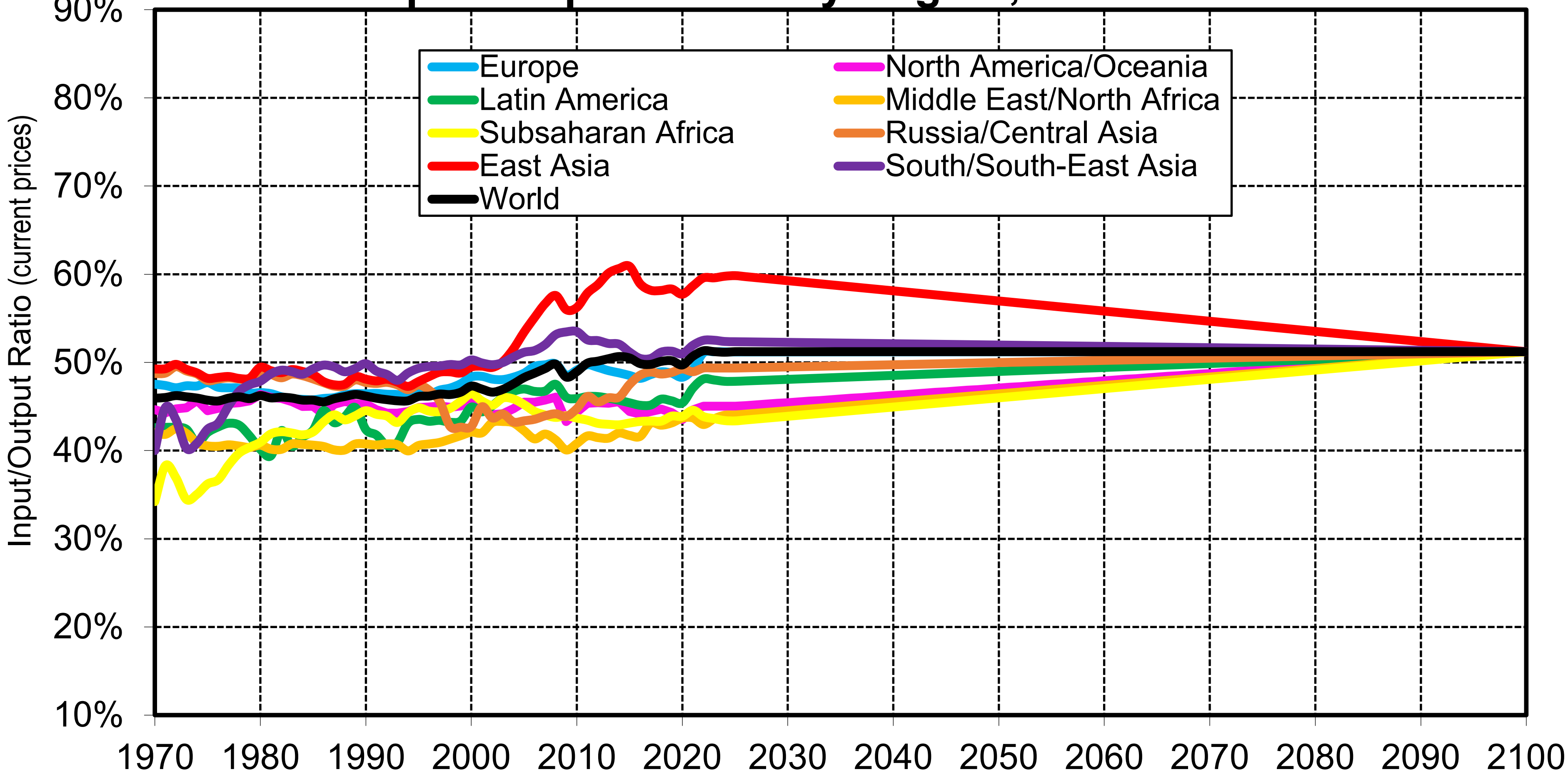
Interpretation. According to the Productivist Convergence and Persistent Inequality scenarios, grazing land declines slightly from 3.2 to 3.0 billions between 2025 and 2100, with small declines in most regions. **Sources and series**: wseed.world (U7b)

Fig. 24c. Cropland by Region Under Persistent Inequality and Productivist Convergence Scenarios, 1800-2100



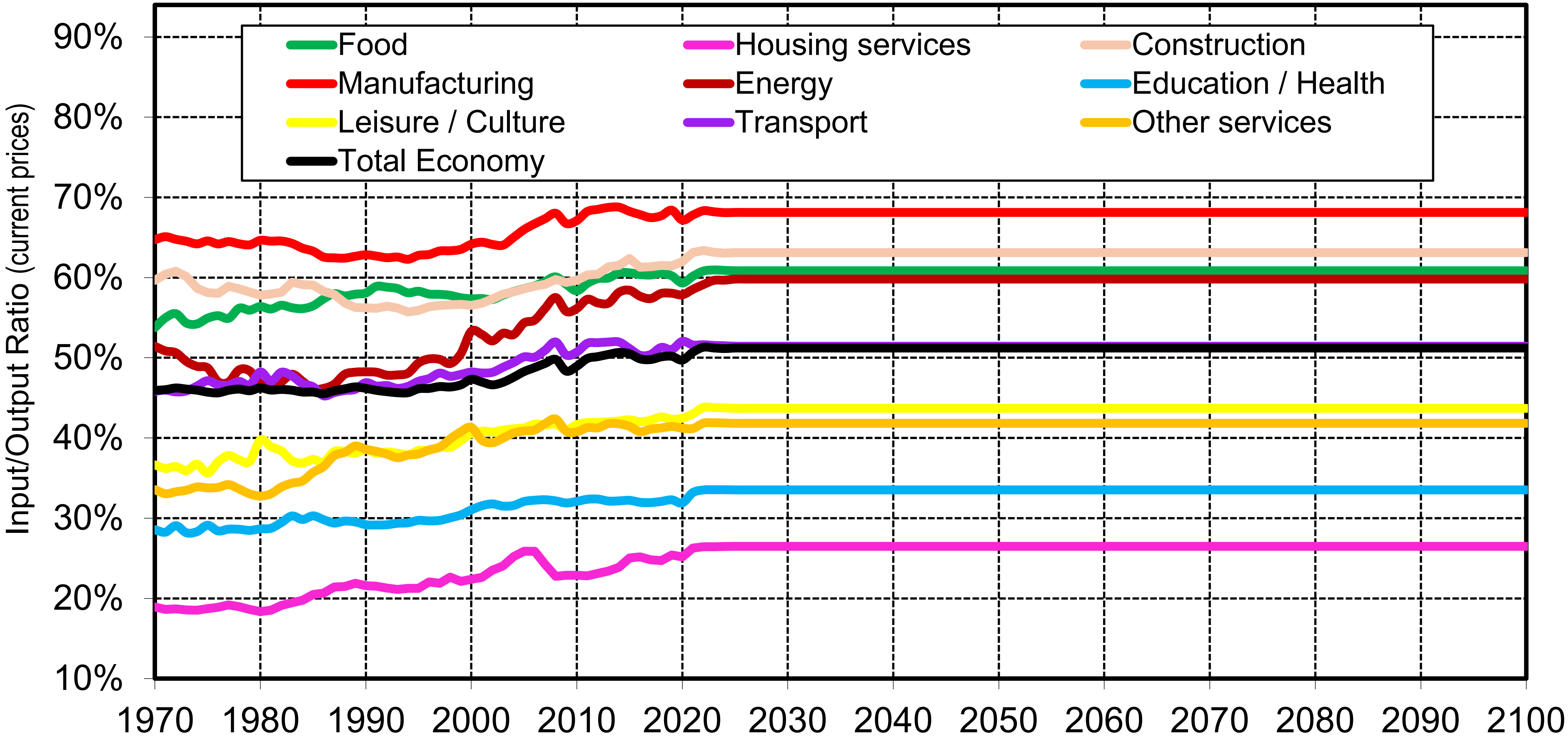
Interpretation. According to the Productivist Convergence and Persistent Inequality scenarios, cropland rises from 1.6 to 2.5 billions between 2025 and 2100, with increases in most regions. **Sources and series**: wseed.world (U7c)

Fig. 25. The Evolution of Input-Output Matrices: Input/Output Ratios by Region, 1970-2100



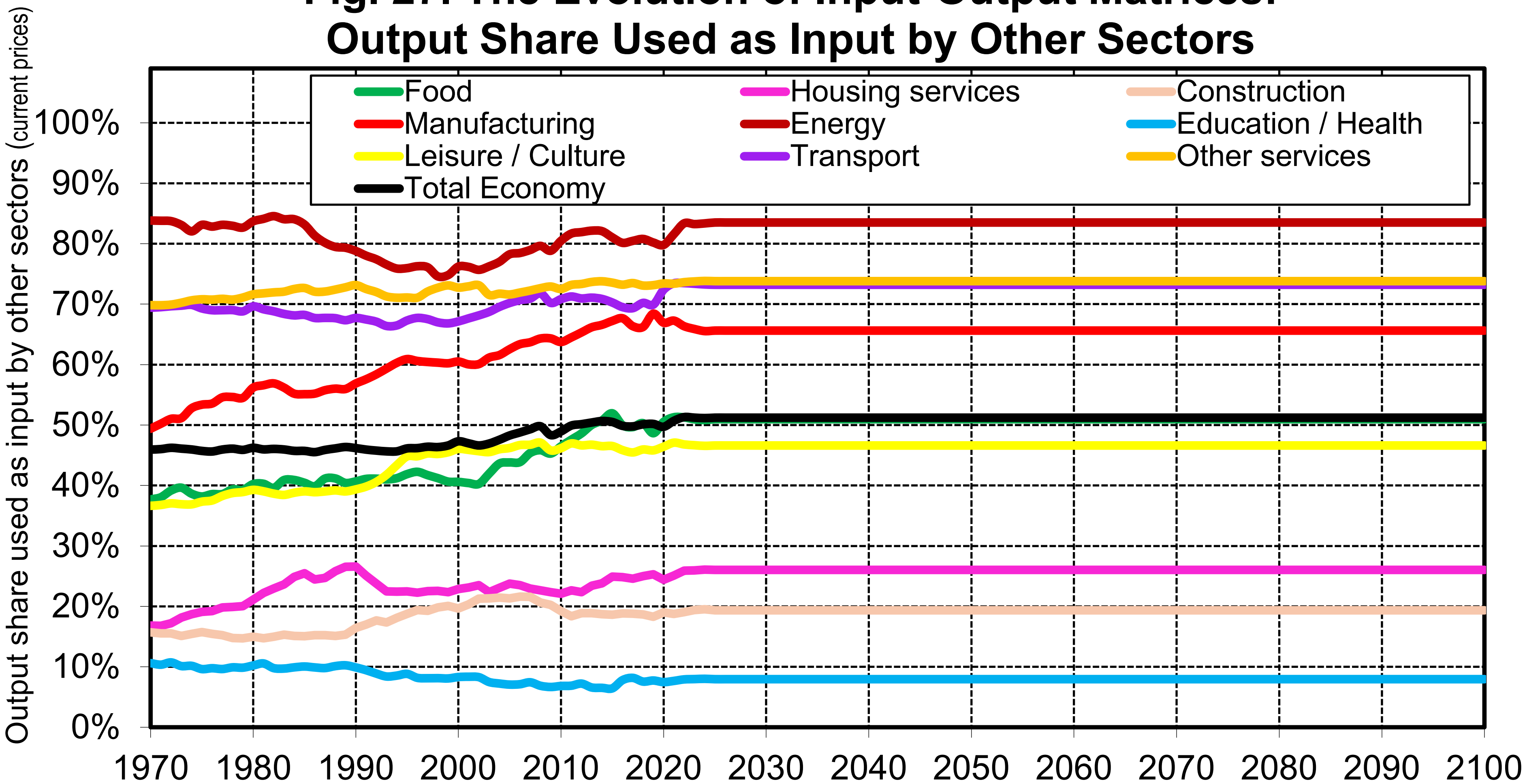
Interpretation. At the world level, intermediate inputs made on average 46% of total output in 1970 (all sectors combined). The global input-output ratio rose to 52% by 2025, with moderate variations across regions. East Asia's high ratio is due to the large manufacturing sector. In our benchmark simulations, we assume that this ratio will converge to 52% in all countries by 2100. **Sources and series**: wseed.world (O0)

Fig. 26. The Evolution of Input-Ouput Matrices: Input/Output Ratios by Sector, 1970-2100



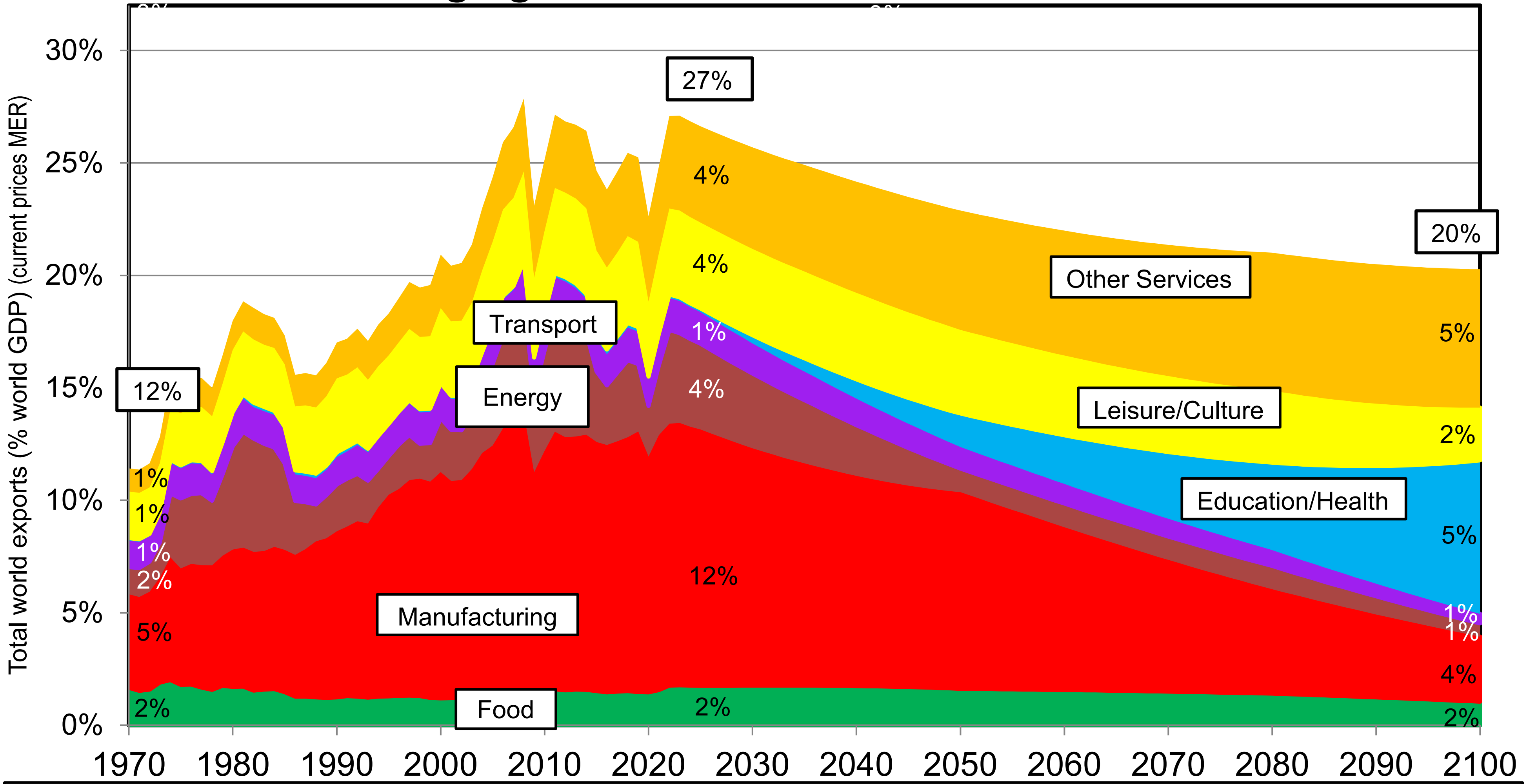
Interpretation. Material sectors like manufacturing, construction, food and energy have always been the most input-intensive (with input-output ratios around 60-70% in 2025), while immaterial sectors like education/health, leisure/culture and other services have always been much less input-intensive (with input-output ratios around 30-40% in 2025). In our benchmark simulations, we assume that each country converges by 2100 to the world average ratio observed in 2025 in each sector . **Sources and series**: wseed.world (O0i)

Fig. 27. The Evolution of Input-Output Matrices: Output Share Used as Input by Other Sectors



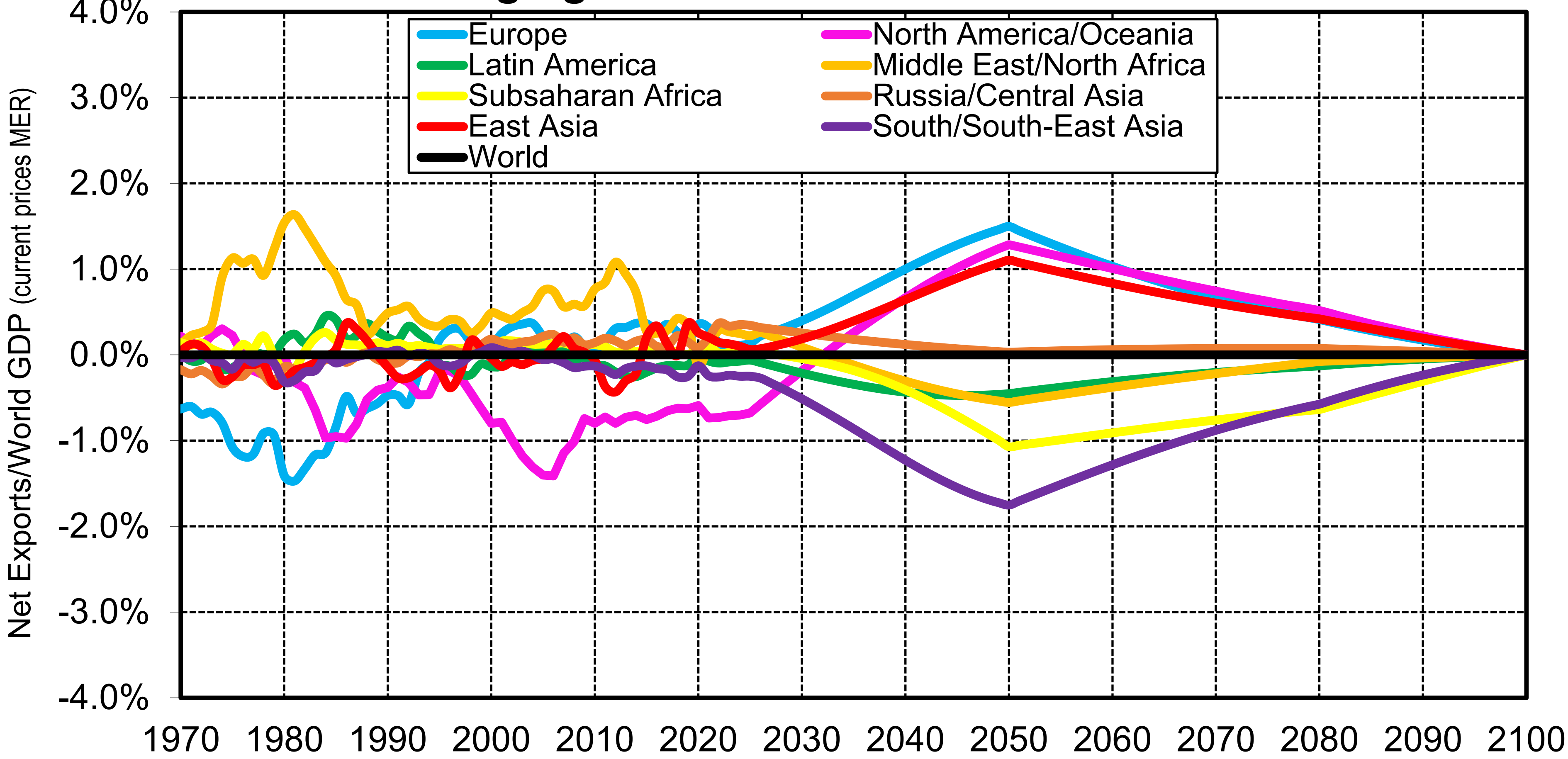
Interpretation. The share of each sector's output that is used as an intermediate input by other sectors (as opposed to the share that is used as final expenditure) has always been highest in energy (over 80% in 2025), followed by transport, other services and manufacturing (65-75%), food & leisure/culture (45-50%), construction & housing services (20-25%) and education/health (less than 10%). In our benchmark simulations, we assume that each country converges by 2100 to the average share observed in 2025 in each sector. **Sources and series**: wseed.world (O0s)

Fig. 28. Sustainable Convergence Scenario: The Changing Structure of Global Trade Flows 1970-2100



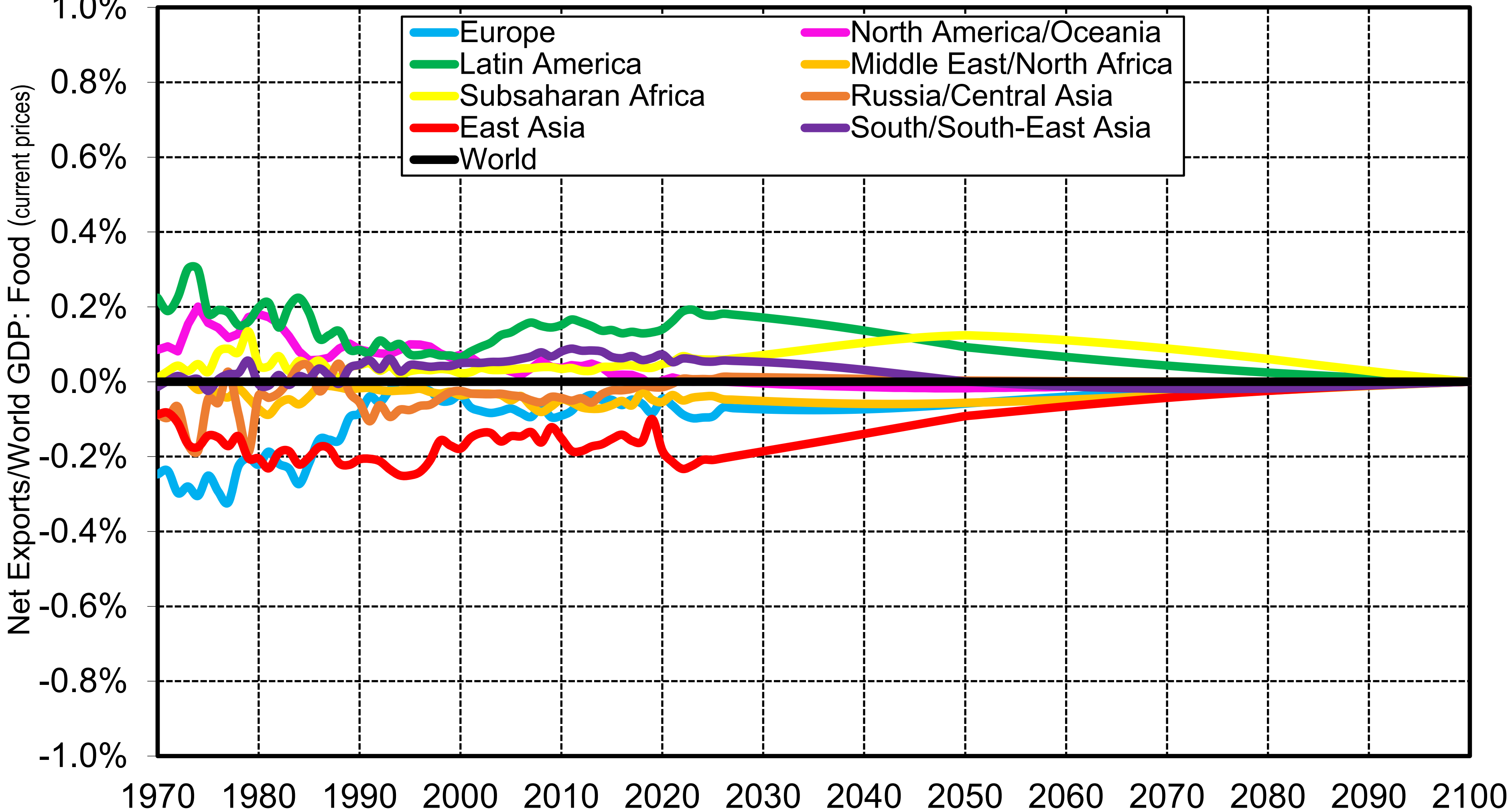
Interpretation. Total world exports rose from 12% of world GDP in 1970 to 20% in 2000 and 27% in 2008. They then stabilized around 26-27% between 2008 and 2025 and are projected to decline to 20% by 2100 according to the Sustainable Convergence scenario, with a sharp decline in material trade (mostly due to the fall in the share of material sectors in global GDP), partly compensated by the projected rise in immaterial trade. **Note.** Exports in housing/construction (less than 0.1% world GDP) are included in manufacturing. **Sources and series**: wseed.world (Q0)

Fig. 29. Sustainable Convergence Scenario: The Changing Pattern of Trade Balance/World GDP

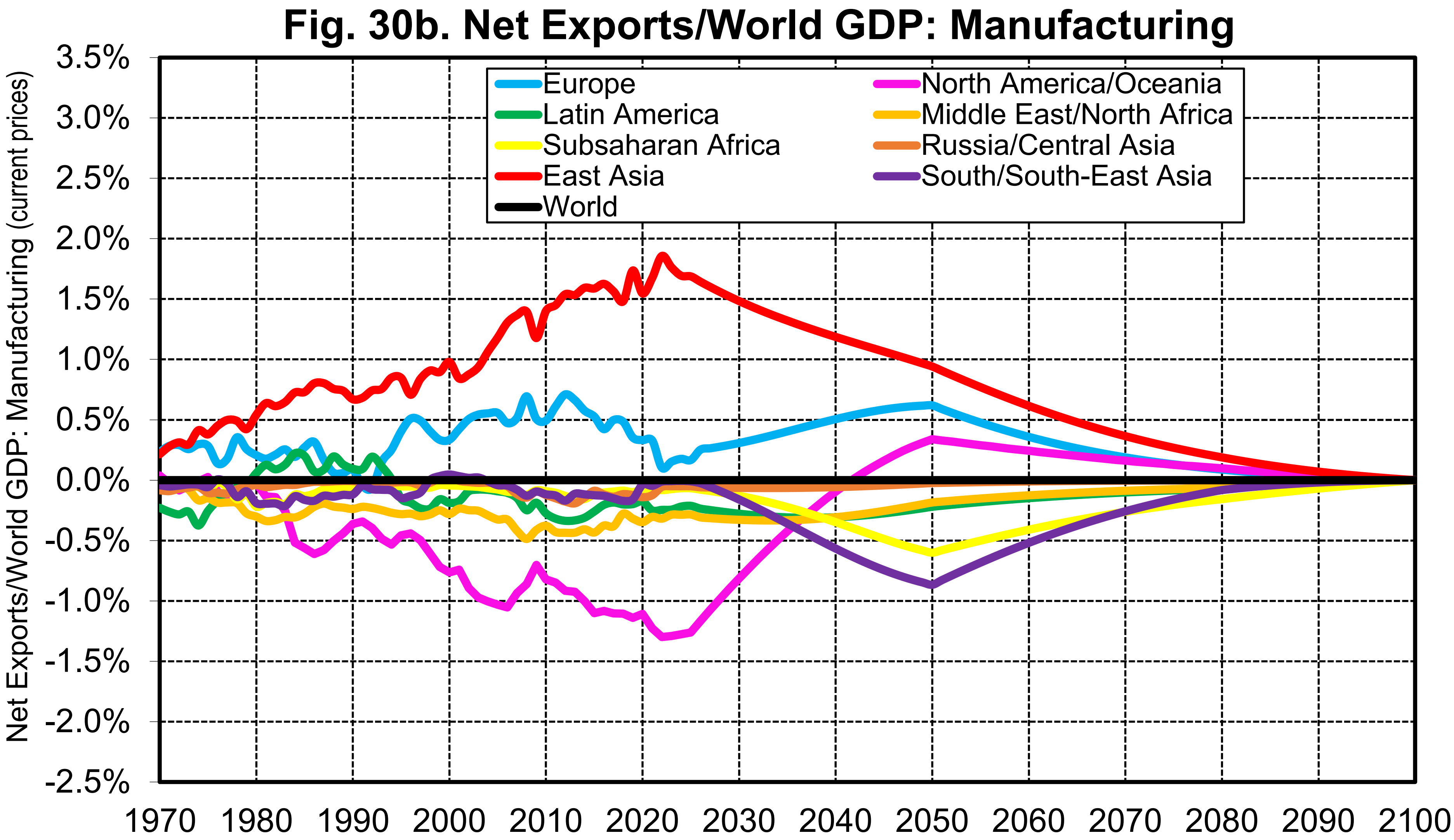


Interpretation. In the Sustainable Convergence scenario, all countries are projected to have balanced trade in all sectors by 2100. During the 2025-2100 transition period, we assume trade deficits in poor countries vis-a-vis rich countries, as a counterpart to large investment flows (manufacturing equipment, energy infrastructures, etc.) and human capital expenditure in poor countries. **Sources and series**: wseed.world (Q0nw)

Fig. 30a. Net Exports/World GDP: Food

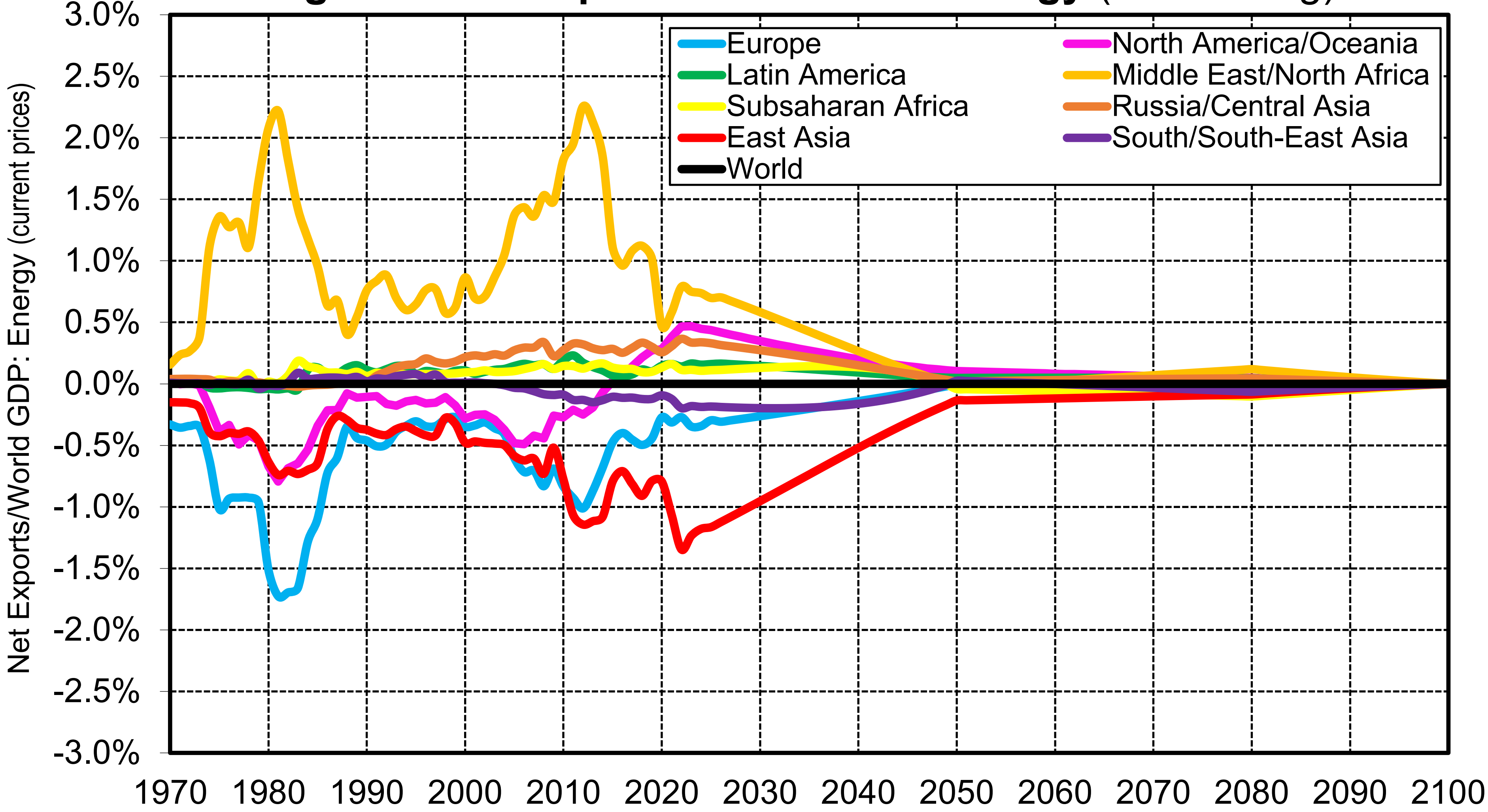


Observed series 1970-2025. Projected series 2025-2100 (benchmark scenario). **Sources and series**: wseed.world (Q1nw)

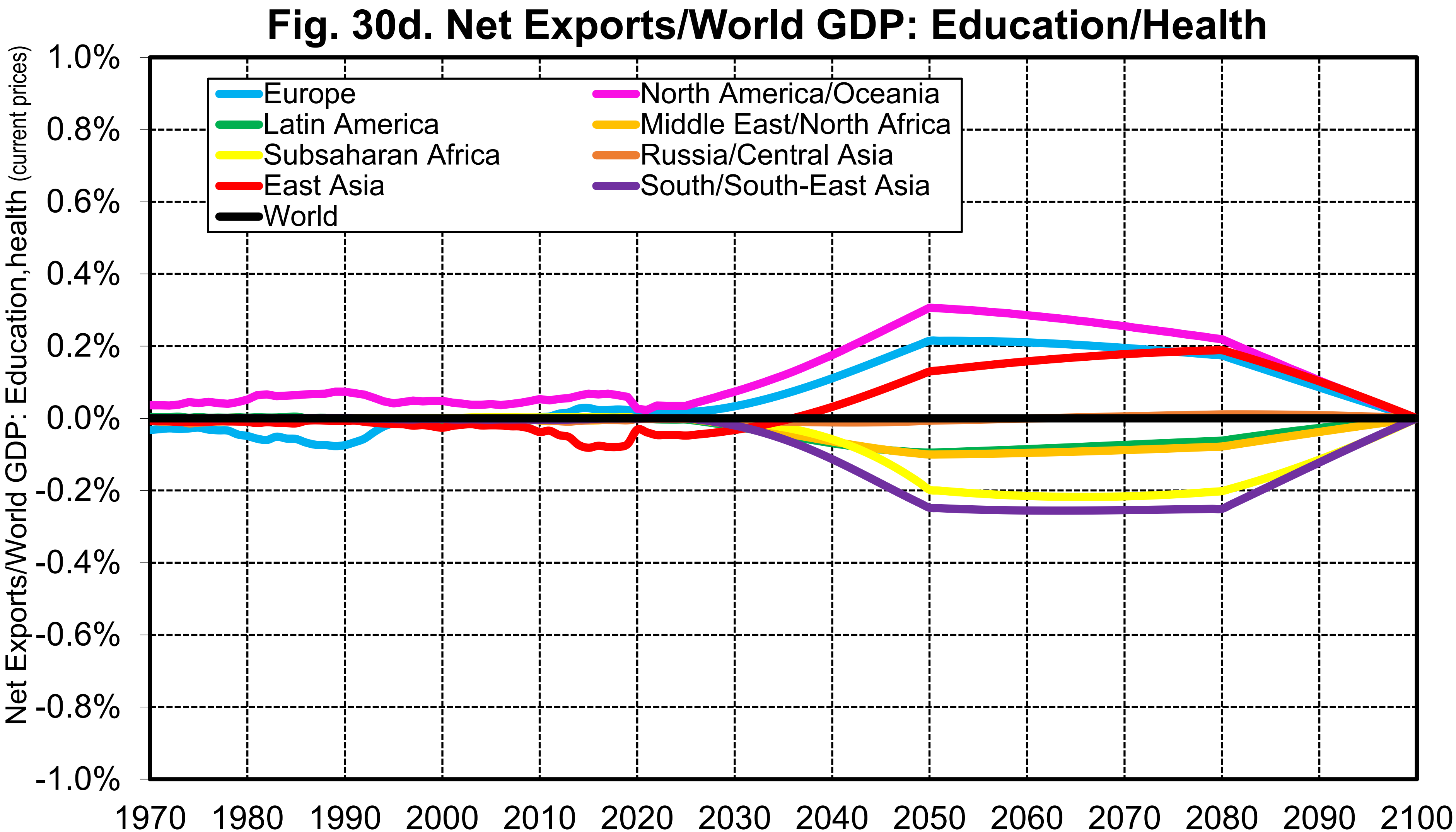


Observed series 1970-2025. Projected series 2025-2100 (benchmark scenario). **Sources and series**: wseed.world (Q3nw)

Fig. 30c. Net Exports/World GDP: Energy (incl. Mining)

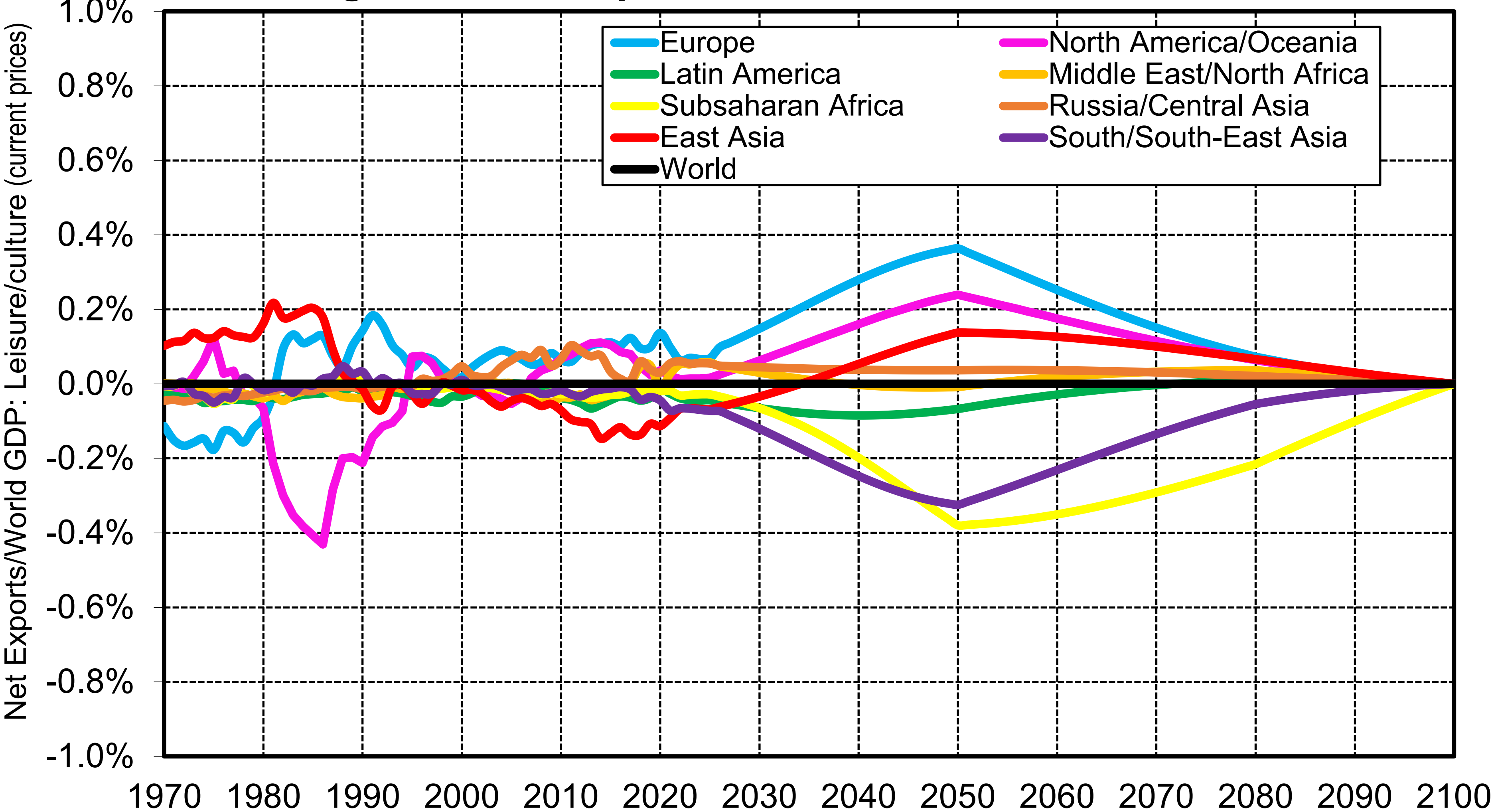


Observed series 1970-2025. Projected series 2025-2100 (benchmark scenario). **Sources and series**: wseed.world (Q4nw)



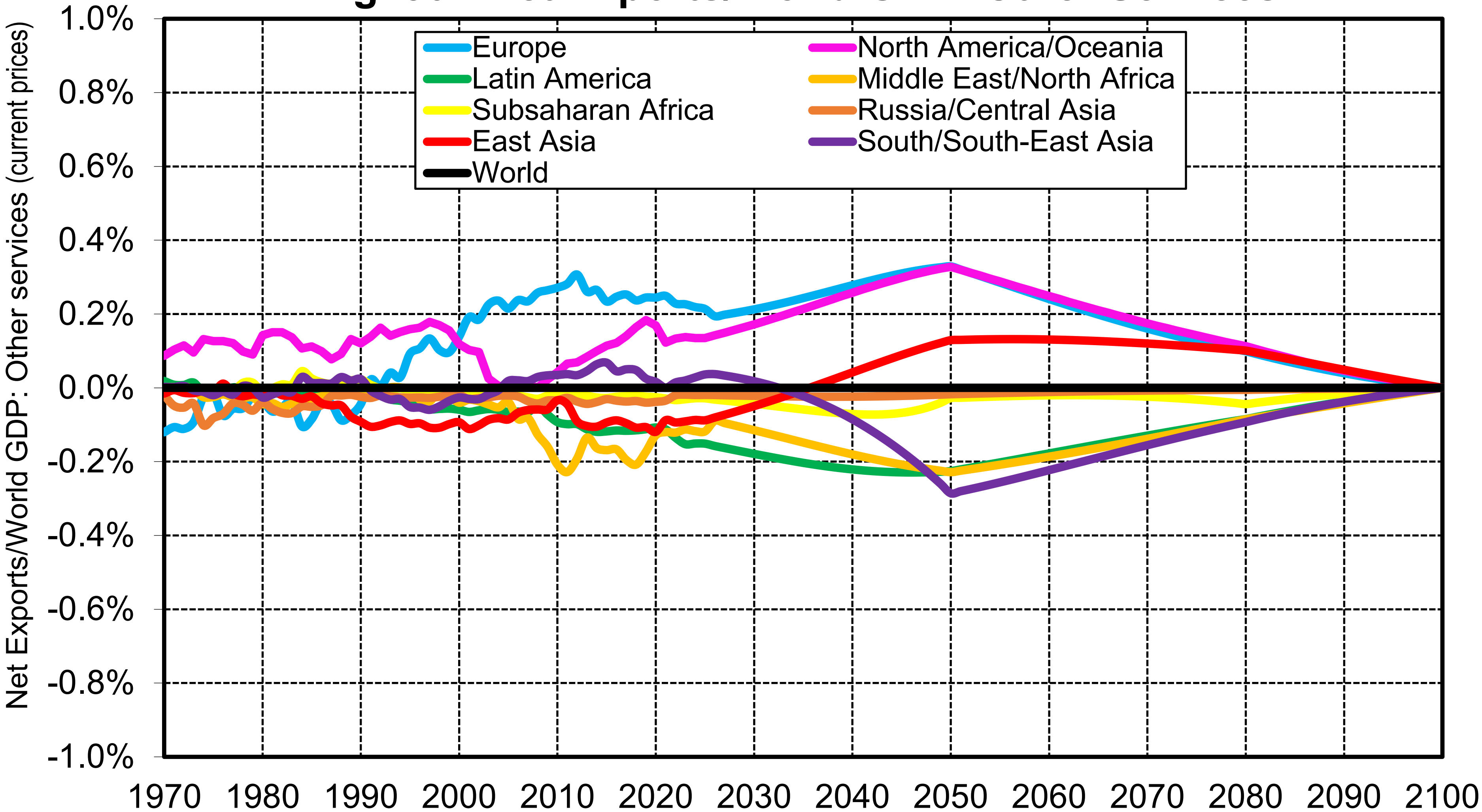
Observed series 1970-2025. Projected series 2025-2100 (benchmark scenario). **Sources and series**: wseed.world (Q5nw)

Fig. 30e. Net Exports/World GDP: Leisure/Culture



Observed series 1970-2025. Projected series 2025-2100 (benchmark scenario). **Sources and series**: wseed.world (Q6nw)

Fig. 30f. Net Exports/World GDP: Other Services

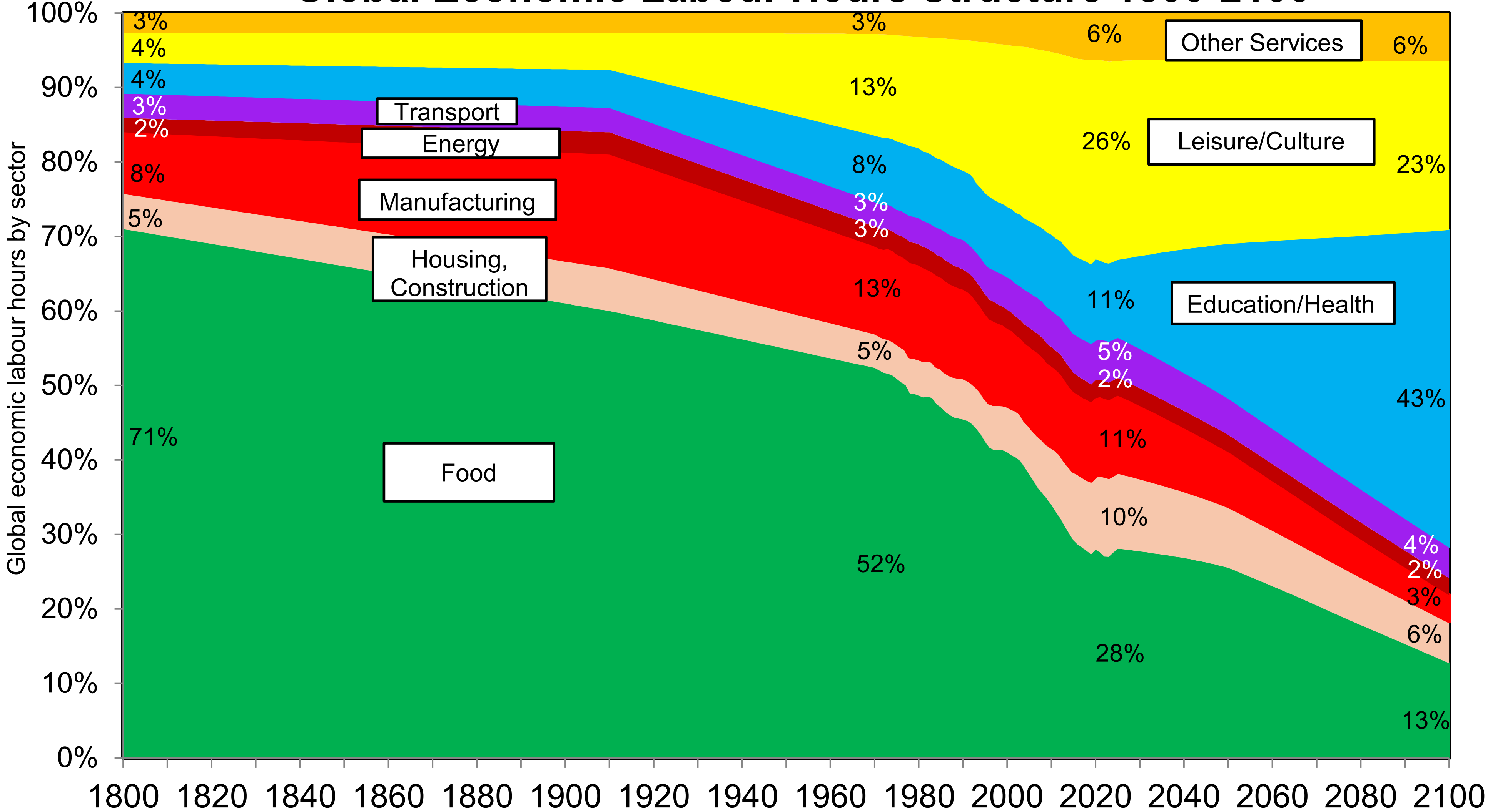


Observed series 1970-2025. Projected series 2025-2100 (benchmark scenario). **Sources and series**: wseed.world (Q8nw)

Table 13. Sectoral Productivity Growth Rates, 1970-2200															
		Total Economy	**Material sectors**	Food	Housing/ Construction	incl. Housing services	incl. Construction	Manufacturing Goods	Energy	Transport	**Immaterial sectors**	Education Health	Leisure Culture	Other Services
Annual productivity growth rate (PPP Euros 2025)	1970-2025	**1.5%**	**1.8%**	2.0%	-0.2%	1.8%	-0.9%	2.1%	0.7%	1.0%	**0.8%**	0.8%	0.7%	1.2%
	2025-2100	**2.5%**	**3.1%**	3.3%	2.5%	2.5%	2.5%	3.4%	2.7%	2.9%	**2.0%**	1.4%	2.6%	2.3%
	2100-2200	**0.8%**	**1.6%**	1.5%	1.3%	1.3%	1.3%	1.7%	1.3%	1.7%	**0.7%**	0.5%	1.3%	0.5%

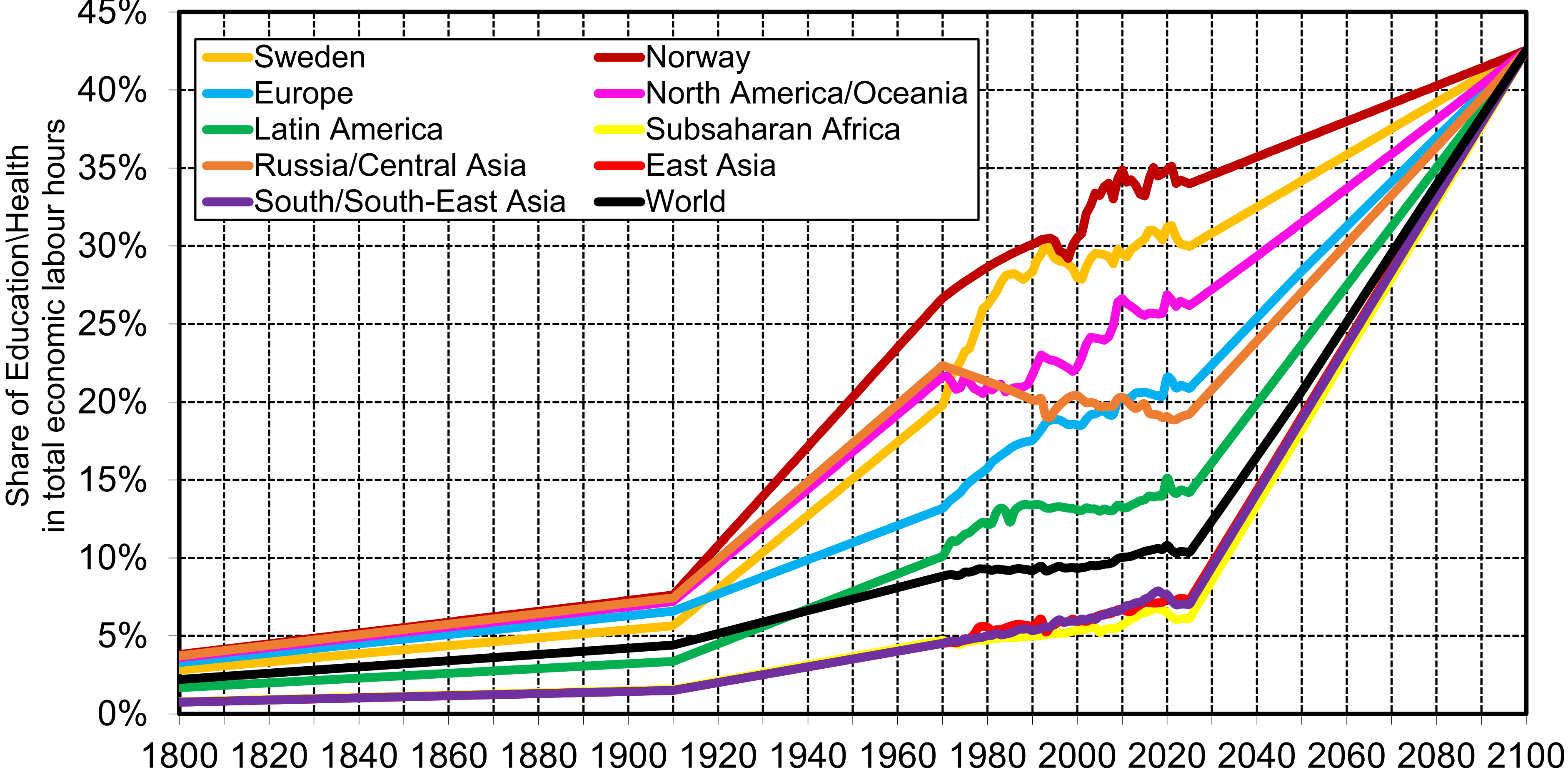
Interpretation. The growth rate of productivity (hourly GDP) has generally been higher in material sectors than in immaterial sectors in the past (with an average gap around 1% per year over the 1970-2025), and we assume similar differentials for the future. **Source:** wseed.world (F1b)

Fig. 31. Planetary Habitability & Structural Transformation: Global Economic Labour Hours Structure 1800-2100

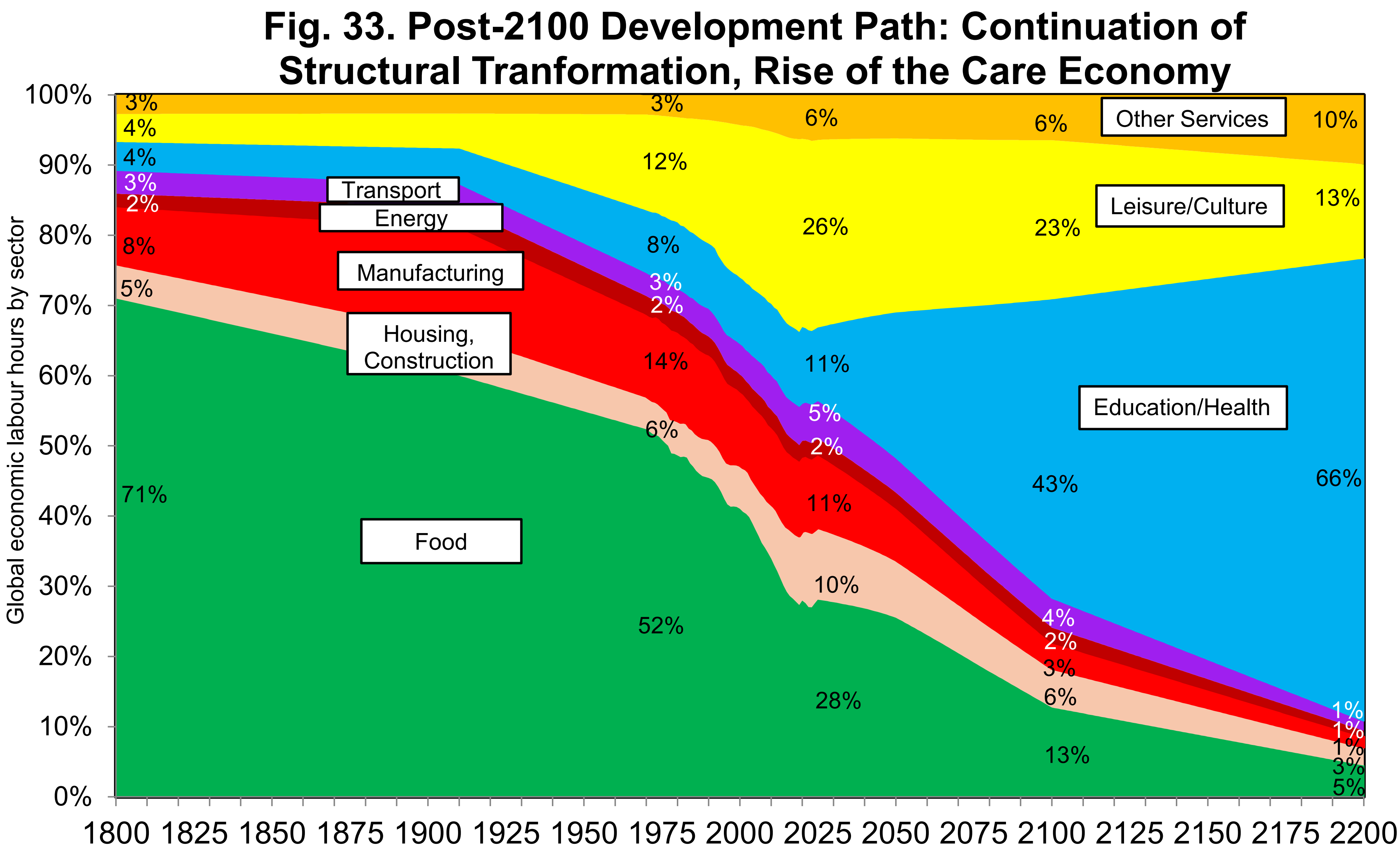


Interpretation. At the world level, the share of food production in total economic labour hours dropped from 71% in 1800 to 52% in 1970 and 28% in 2025, and is scheduled to drop to about 13% by 2100 in our benchmark scenario. **Sources and series** : wseed.world (E1l)

Fig. 32. The Ongoing Rise of Education, Health & Public Services

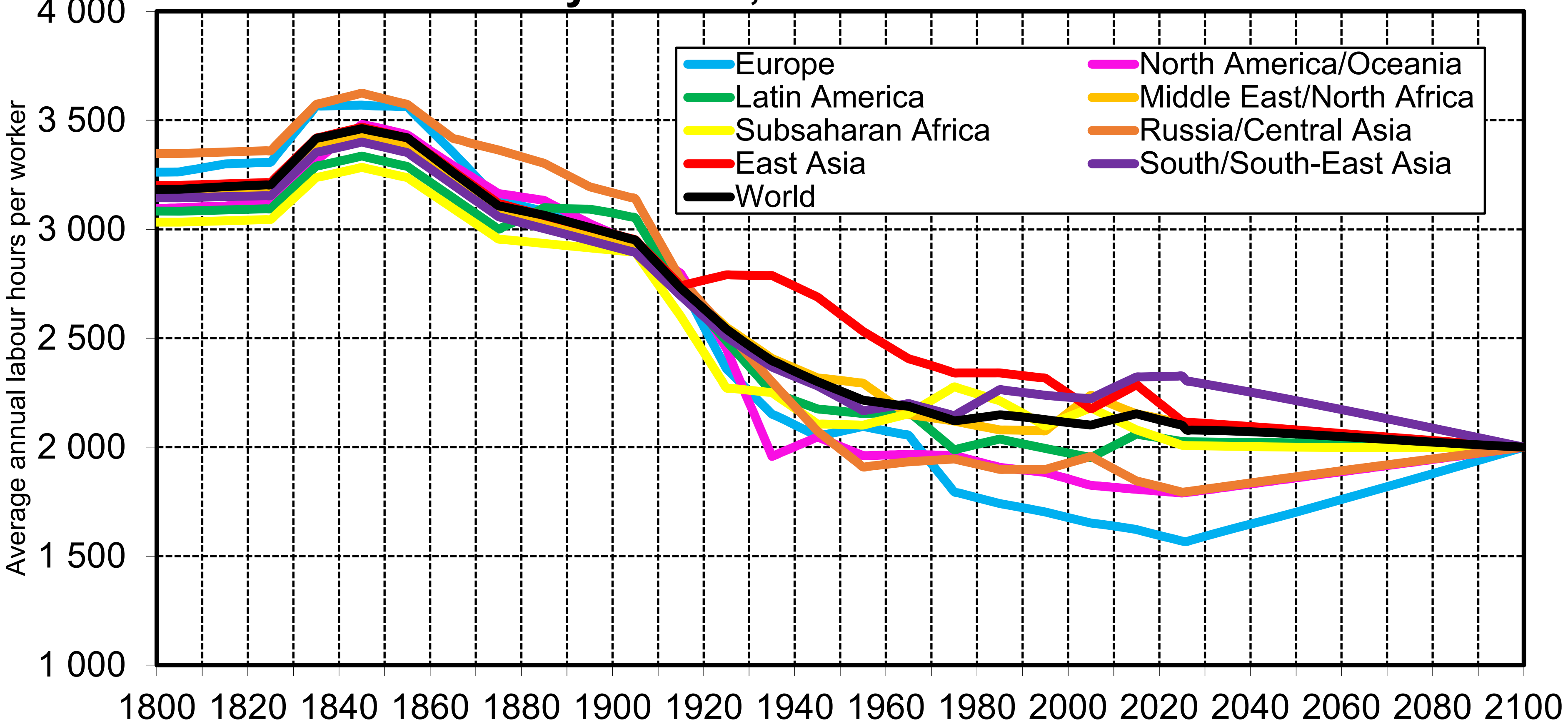


Interpretation. At the world level, the share of education, health and public services in total economic labour hours rose from 2% in 1800 to 8% in 1970, 11% in 2025 and is scheduled to rise to 43% by 2100 under the Sustainable Convergence scenario. In 2025, it is already around 30-35% of total economic labour hours in Sweden and Norway. **Sources and series**: wseed.world (E1m)



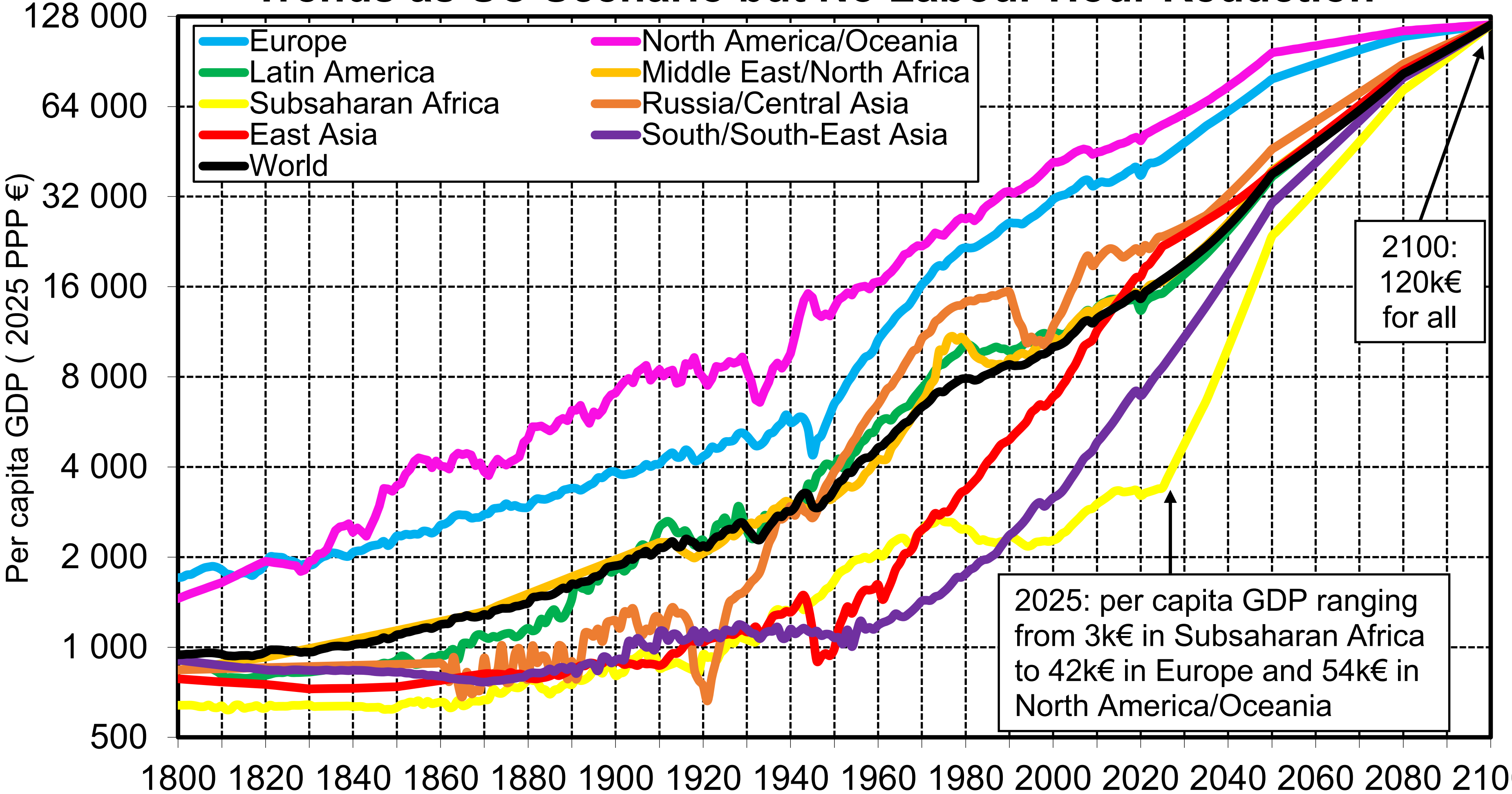
Interpretation. Because they are characterized by slower technical change than other sectors, care economy sectors (education, health) are projected to absorb a rising fraction of labour hours in the future. **Sources and series** : wseed.world (E1n)

Fig. 34. Productivist Convergence Scenario 2025-2100: Same Productivity Trends, but No Labour Hour Reduction



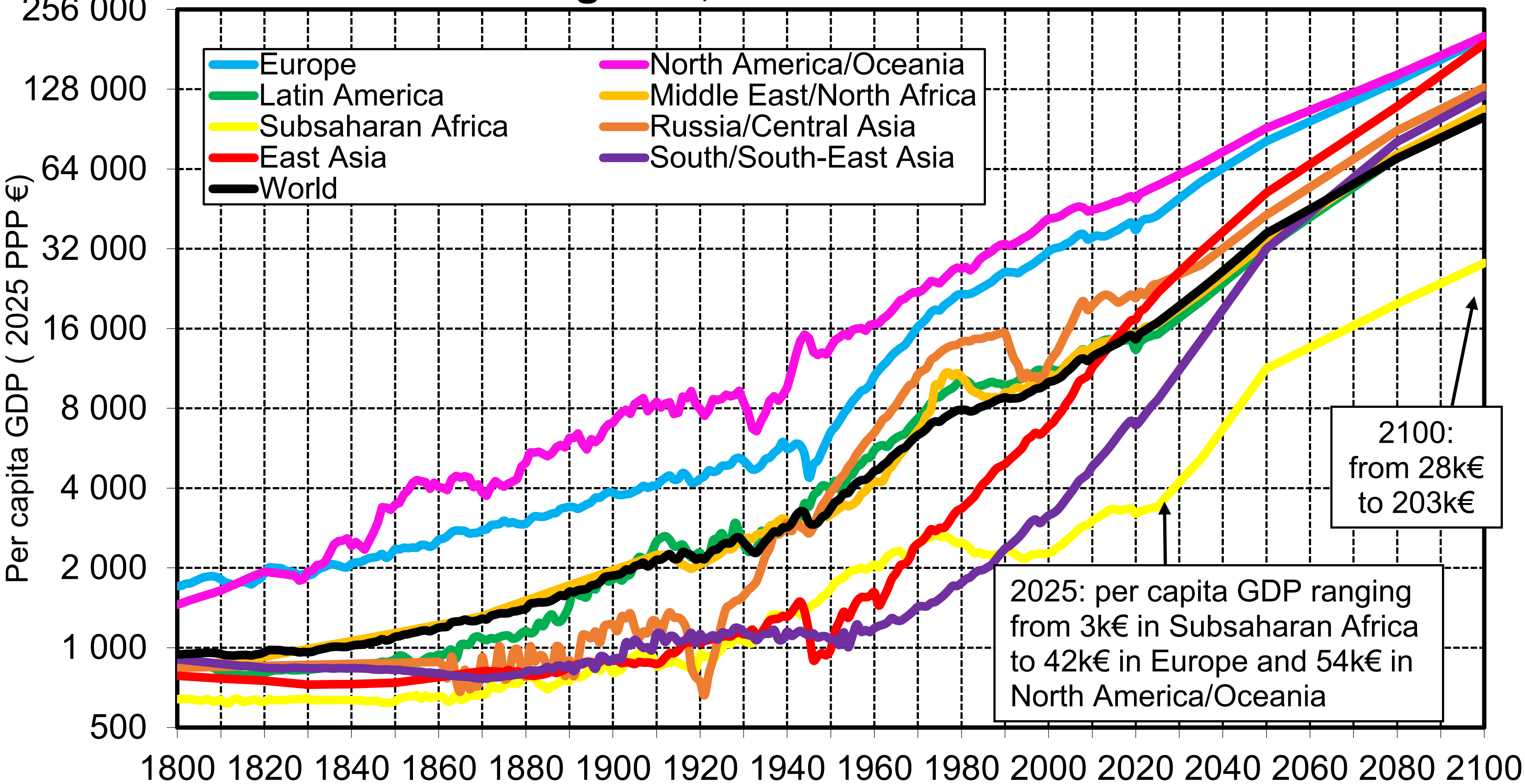
Interpretation. According to the Productivist Convergence scenario, productivity growth follows the same trend over the 2025-2100 period as in the Sustainable Convergence scenario (with hourly productivity equal to 125 Euros PPP 2025 in all countries by 2100), but without any major reduction of labour hours. I.e. annual labour hours per worker are assumed to converge in all countries toward 2000 hours over the 2025-2100 period (as compared to a world average equal to 2100 hours in 2025). **Sources and series**: wseed.world (E1i)

Fig. 35. Productivist Convergence: Same Productivity Trends as SC Scenario but No Labour Hour Reduction



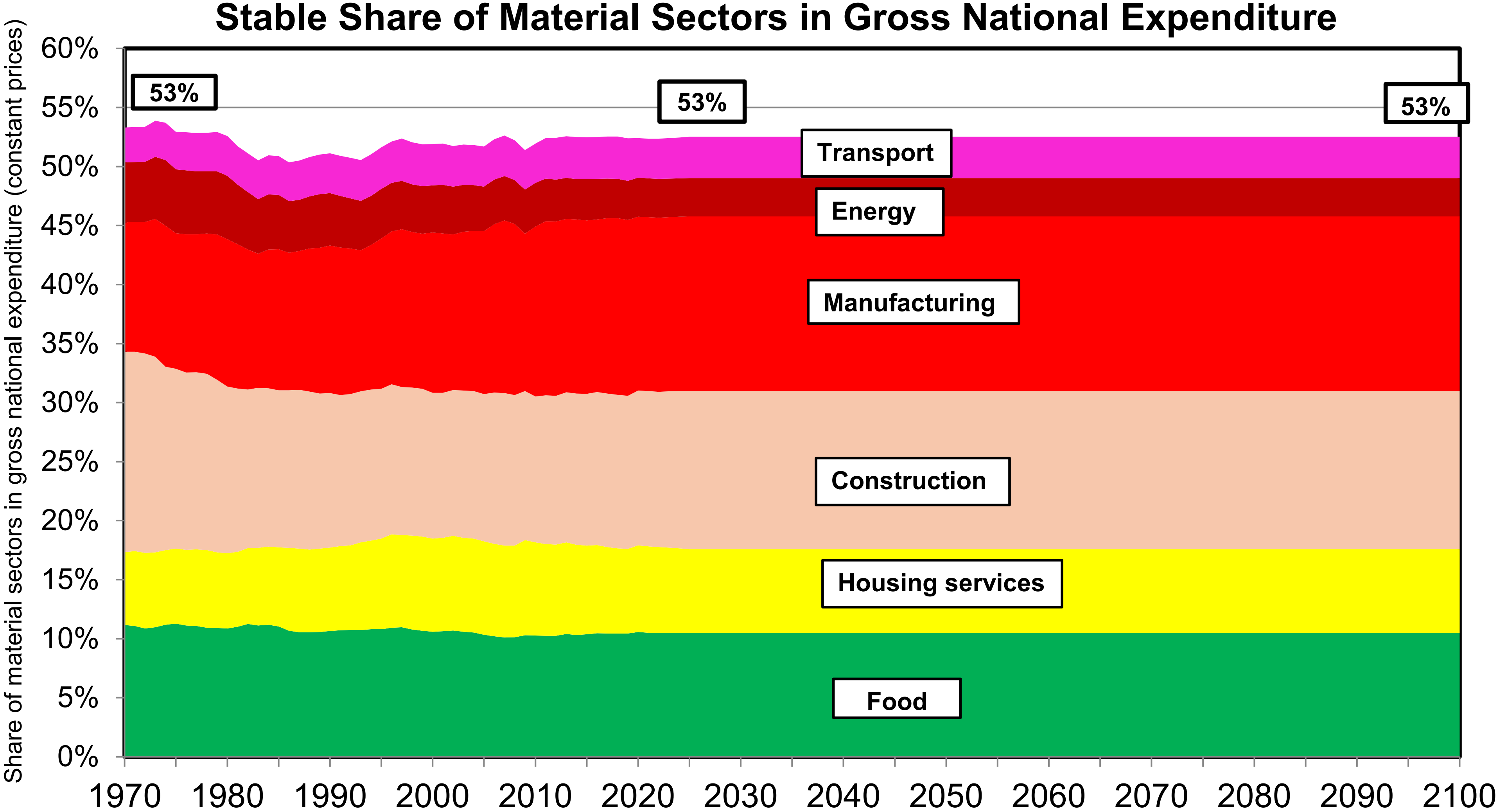
Interpretation. In the "productivist convergence" scenario, we assume the same productivity trends as in "sustainable convergence" but with no reduction in labour hours, resulting in much larger per capita GDP levels (120k€ rather than 60k€). **Sources and series**: wseed.world (A1d)

Fig. 36. Persistent Inequality Scenario: Partial Productivity Convergence, No Labour Hour Reduction



Interpretation. In the "persistent inequality" scenario, we assume partial convergence in productivity levels (following patterns observed over the 1990-2025 period) and no reduction in labour hours, resulting in persistent inequality in per capita GDP. **Sources and series**: wseed.world (A1e)

Fig. 37. Productivist Convergence & Persistent Inequality: Stable Share of Material Sectors in Gross National Expenditure



Interpretation. The share of material sectors in gross national expenditure (final consumption and investement) remained stable at 53% at the world level between 1970 and 2025. It is a projected to remain stable around 53% between 2025 and 2100 according to our productivist convergence and persistent inequality scenarios. **Sources and series**: wseed.world (G0p)

Table 14. Per Capita GDP Growth Rates, 1950-2100 : Comparing Sustainable Convergence (SC), Productivist Convergence (PC) and Persistent Inequality (PI) Scenarios

Annual growth rates of per capita GDP (2025 PPP Euros)		World	Europe	North America/ Oceania	Latin America	Middle East/North Africa	Subsaharan Africa	Russia/ Central Asia	East Asia	South & South-East Asia
1950-1990		**2.4%**	3.5%	2.3%	2.3%	2.7%	0.9%	3.5%	**4.1%**	2.0%
1990-2025		**1.9%**	1.4%	1.5%	1.3%	1.7%	1.1%	1.2%	**4.3%**	3.8%
2025-2100	Sustainable Convergence	**1.7%**	0.5%	0.1%	1.8%	1.7%	**3.9%**	1.3%	1.4%	2.6%
	Productivist Convergence	**2.7%**	1.4%	1.0%	2.8%	2.7%	4.9%	2.2%	2.3%	3.6%
	Persistent Inequality	**2.4%**	2.1%	1.7%	2.6%	2.5%	2.9%	2.3%	2.9%	3.6%

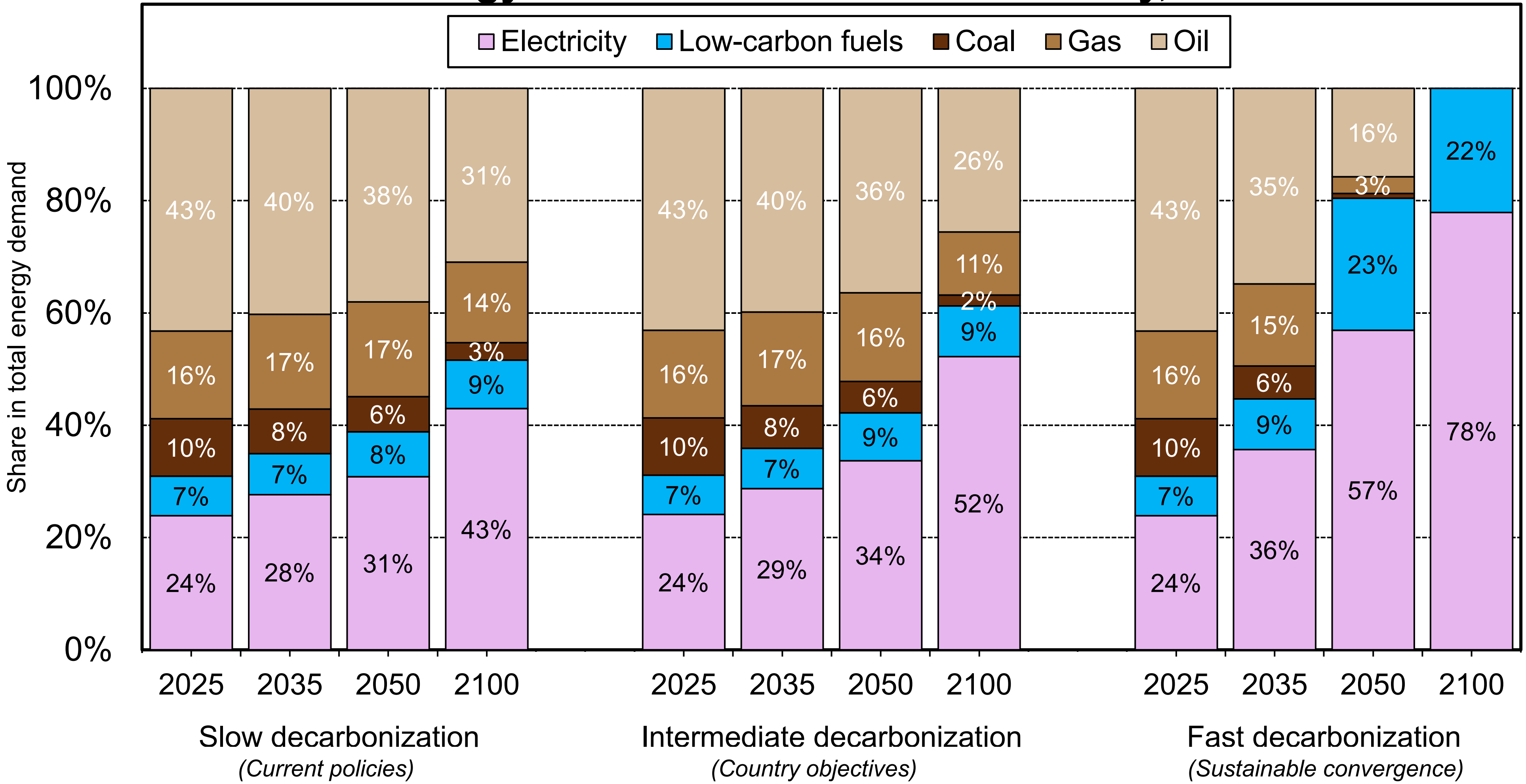
Interpretation. Projected per capital GDP growth rates for Subsaharan Africa over the 2025-2100 period under the Sustainable Convergence scenario are high (close to 4% per year on average), but not higher than those observed in East Asia over the 1950-2025 period. **Source:** wseed.world (A1b)

Table 15. Comparison between per capita GDP Projections of our Three Scenarios versus SSP-IPCC scenarios

	World Region	Sustainable Convergence (SC)	Productivist Convergence (PC)	Persistent Inequality (PI)	SSP1 *("Sustainability")*	SSP2 *("Middle of the road")*	SSP3 *("Regional rivalry")*	SSP4 *("Inequality")*	SSP5 *("Fossil-fueled development")*
Per-Capita GDP, Growth Rate 2025 - 2100 (%)	East Asia	1.4%	2.3%	2.9%	1.2%	1.1%	0.6%	1.0%	1.6%
	Europe	0.5%	1.4%	2.1%	1.3%	1.2%	0.3%	1.1%	1.9%
	Latin America	1.8%	2.8%	2.6%	2.3%	2.1%	0.9%	2.0%	2.9%
	MENA	1.7%	2.7%	2.5%	1.7%	1.5%	0.6%	1.4%	2.4%
	North America & Oceania	0.1%	1.0%	1.7%	2.2%	2.0%	0.8%	1.8%	2.9%
	Russia & Central Asia	1.3%	2.2%	2.3%	2.2%	2.0%	0.9%	1.9%	2.8%
	South & Southeast Asia	2.6%	3.6%	3.6%	2.0%	1.8%	0.8%	1.5%	2.6%
	Sub-Saharan Africa	3.9%	4.9%	2.9%	3.1%	2.7%	1.4%	2.1%	3.8%
	World	**1.7%**	**2.7%**	**2.4%**	**2.1%**	**1.7%**	**0.6%**	**1.3%**	**2.7%**
Per-Capita GDP in 2100 as ratio of World Per-Capita GDP in 2100	East Asia	100	100	189	113	129	158	183	110
	Europe	100	100	198	151	169	218	244	144
	Latin America	100	100	104	117	128	129	182	117
	MENA	100	100	107	129	134	138	140	128
	North America & Oceania	100	100	202	170	186	290	269	161
	Russia & Central Asia	100	100	129	123	131	148	163	123
	South & Southeast Asia	100	100	121	94	97	90	92	93
	Sub-Saharan Africa	100	100	28	59	52	37	35	61
	World	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

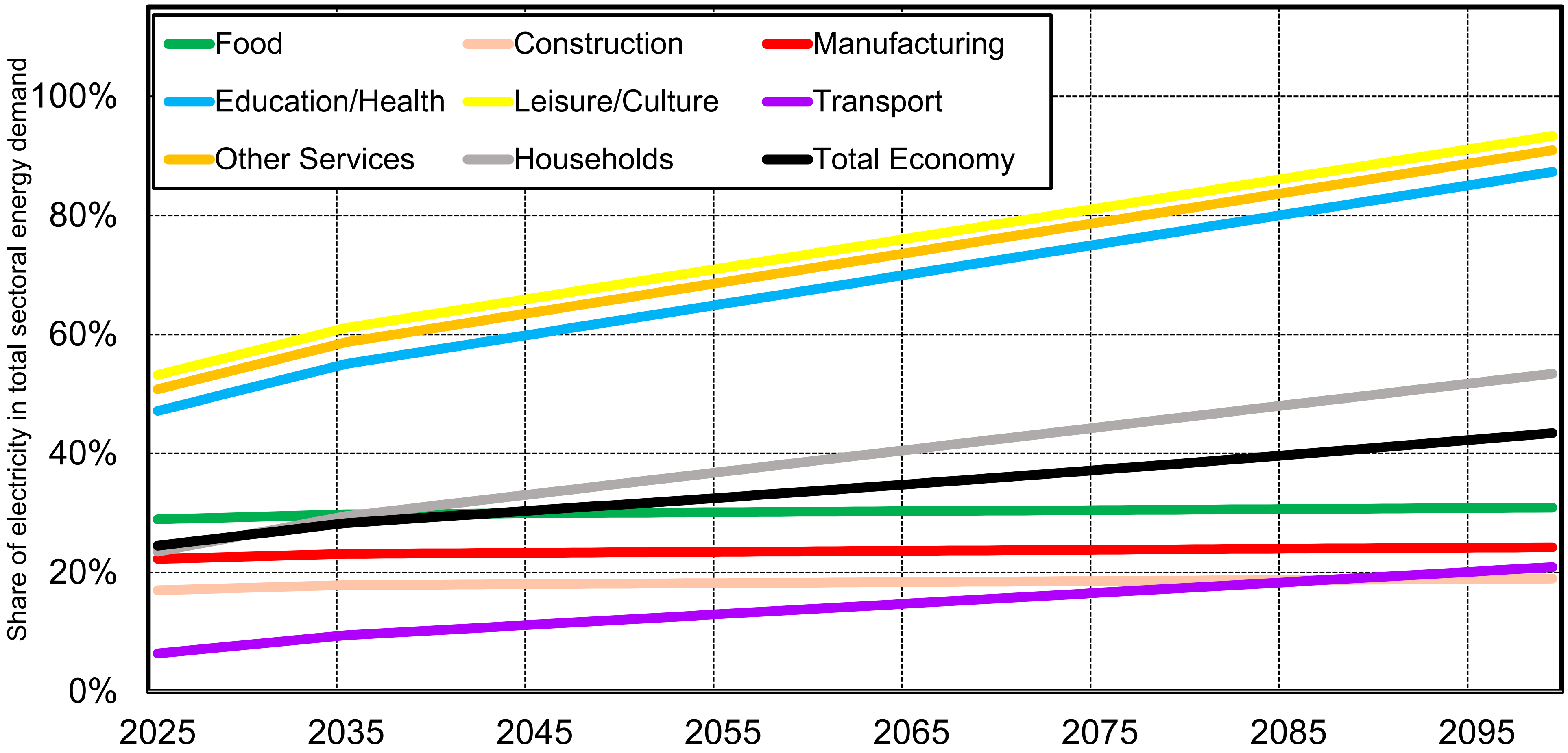
Interpretation. The projected growth rates for world per capita GDP over the 2025-2100 period according to our three scenarios generally fall in the same range as those considered in the SSP scenarios (Shared Socioeconomic Pathways) used in IPCC Reports. The main difference is that SSP scenarios do not consider the possibility of complete convergence: in 2100, the income gap between the poorest and richest regions is around 1 to 3 or more (including in SSP1 and 2). **Sources**: wseed.world (X3b)

Fig. 38. Slow, Intermediate, and Fast Decarbonization: Total Energy Demand of the World Economy, 2025-2100



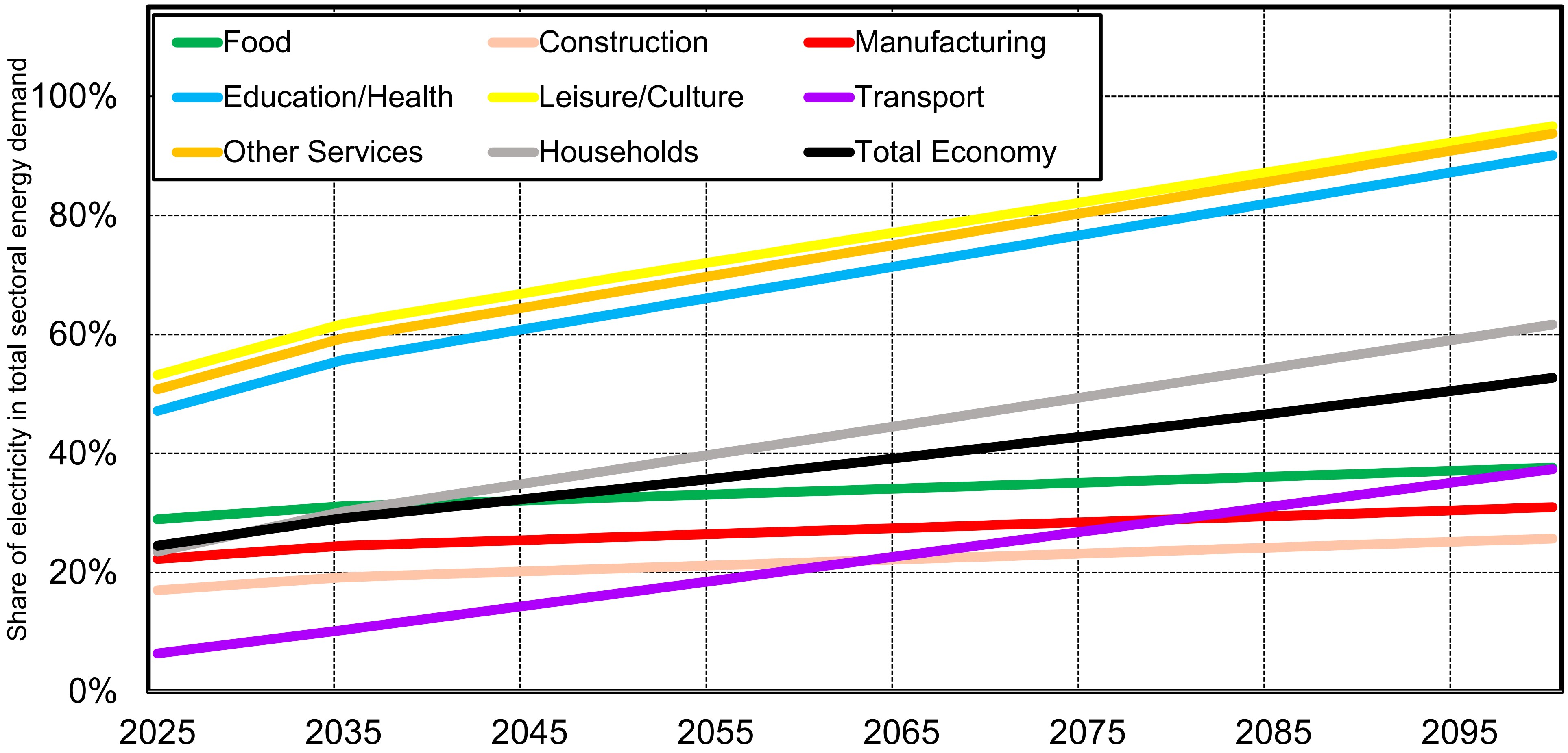
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels (less than 20% of total energy demand of the world economy by 2050 and 0% by 2100) as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives). **Note.** "Electricity" includes district heat production (from CHP plants, heat pumps, and electric boilers), which accounts for 4% of total final energy demand in 2025, compared to 20% for electricity strictly speaking. **Sources and series**: wseed.world (T1)

Fig. 39a. Share of Electrification in Total Energy Demand, Slow Decarbonization Scenario, 2025-2100



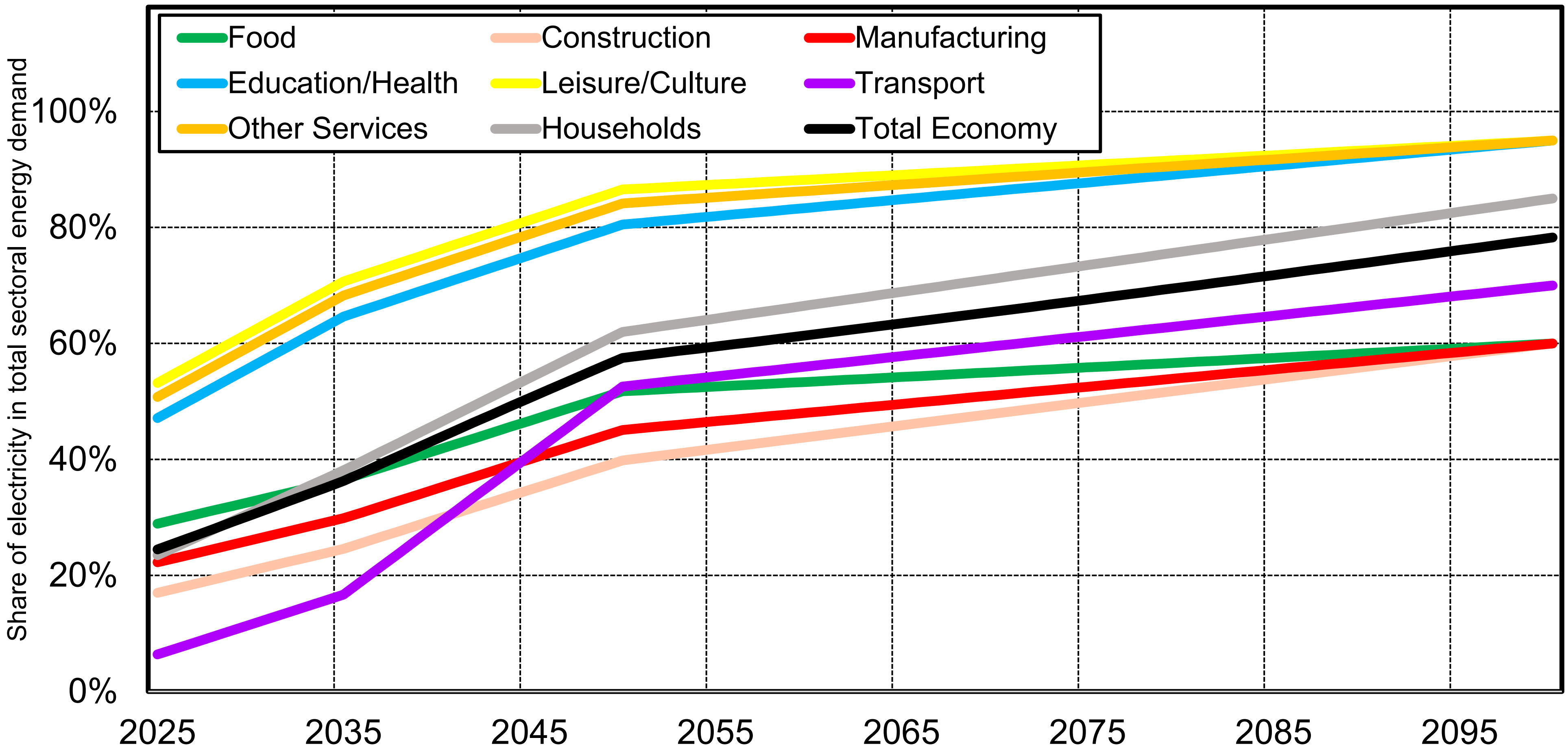
Interpretation. According to the Slow Decarbonization scenario (current policies), the share of electricity in total energy demand is scheduled to rise from 24% in 2025 to 43% in 2100, with large variations across sectors. **Note.** The energy demand of the household sector corresponds to direct energy consumption by households, primarily for residential heating and personal vehicle use. **Sources and series**: wseed.world (T2a)

Fig. 39b. Share of Electrification in Total Energy Demand, Intermediate Decarbonization Scenario, 2025-2100



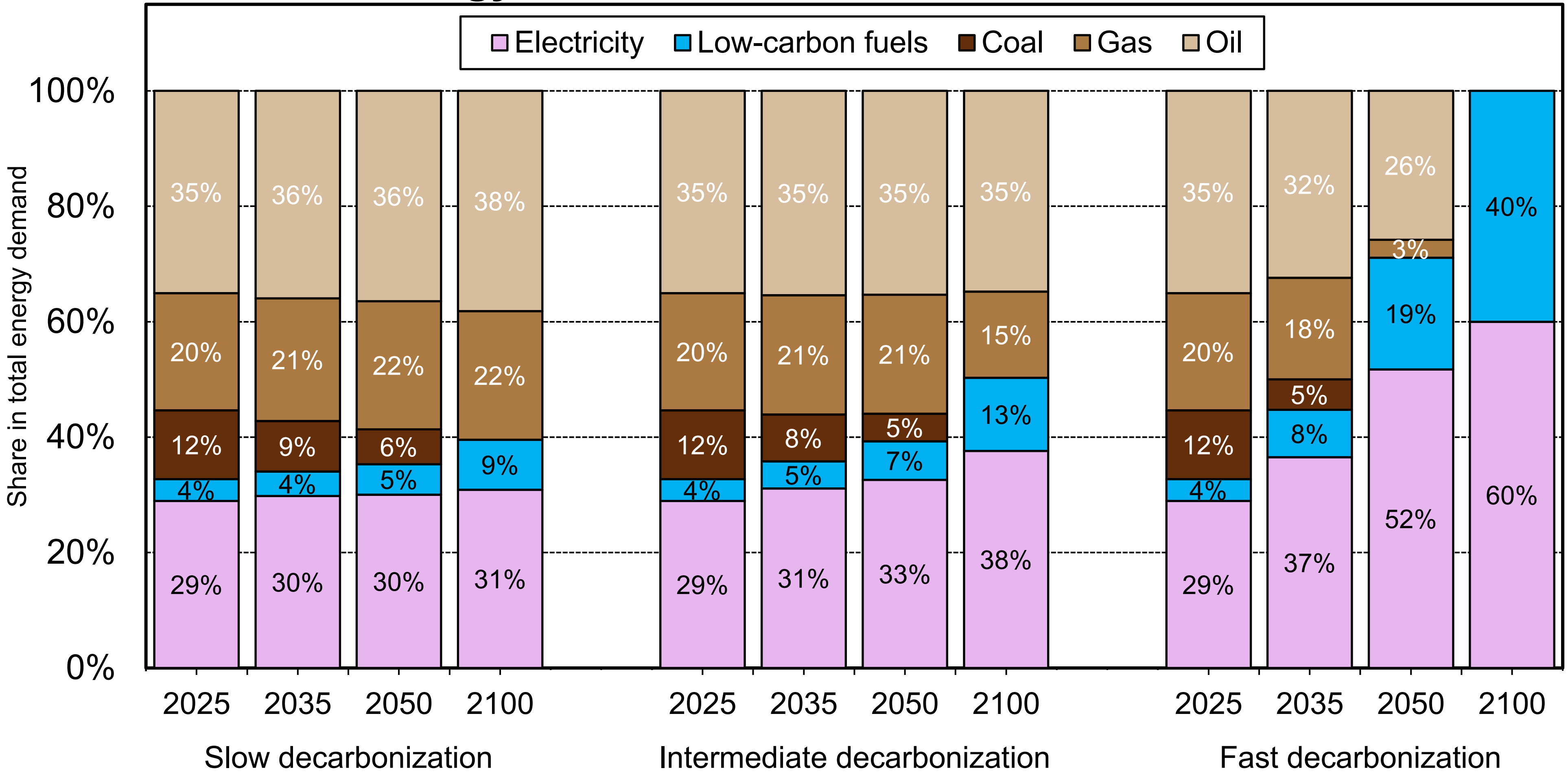
Interpretation. According to the Intermediate Decarbonization scenario (official country commitments and pledges), the share of electricity in total energy demand is scheduled to rise from 24% in 2025 to 53% in 2100, with large variations across sectors. **Note.** The energy demand of the household sector corresponds to direct energy consumption by households, primarily for residential heating and personal vehicle use. **Sources and series**: wseed.world (T2b)

Fig. 39c. Share of Electrification in Total Energy Demand, Fast Decarbonization Scenario, 2025-2100



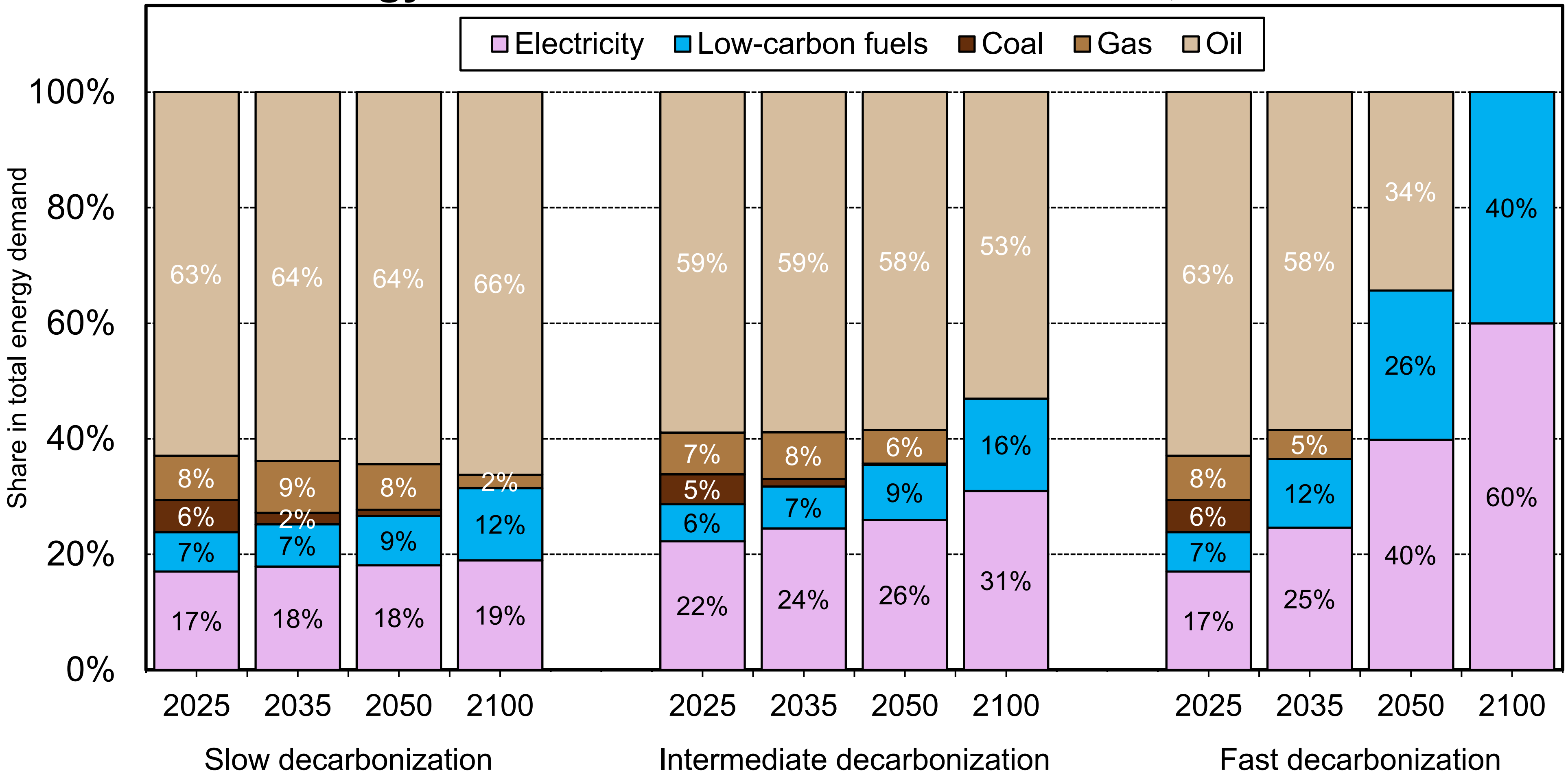
Interpretation. According to the Fast Decarbonization scenario (Sustainable Development), the share of electricity in total energy demand is scheduled to rise from 24% in 2025 to 78% in 2100, with large variations across sectors. **Note.** The energy demand of the household sector corresponds to direct energy consumption by households, primarily for residential heating and personal vehicle use. **Sources and series**: wseed.world (T2c)

Fig. 40a. Slow, Intermediate, and Fast Decarbonization: Energy Demand of the Food Sector, 2025-2100



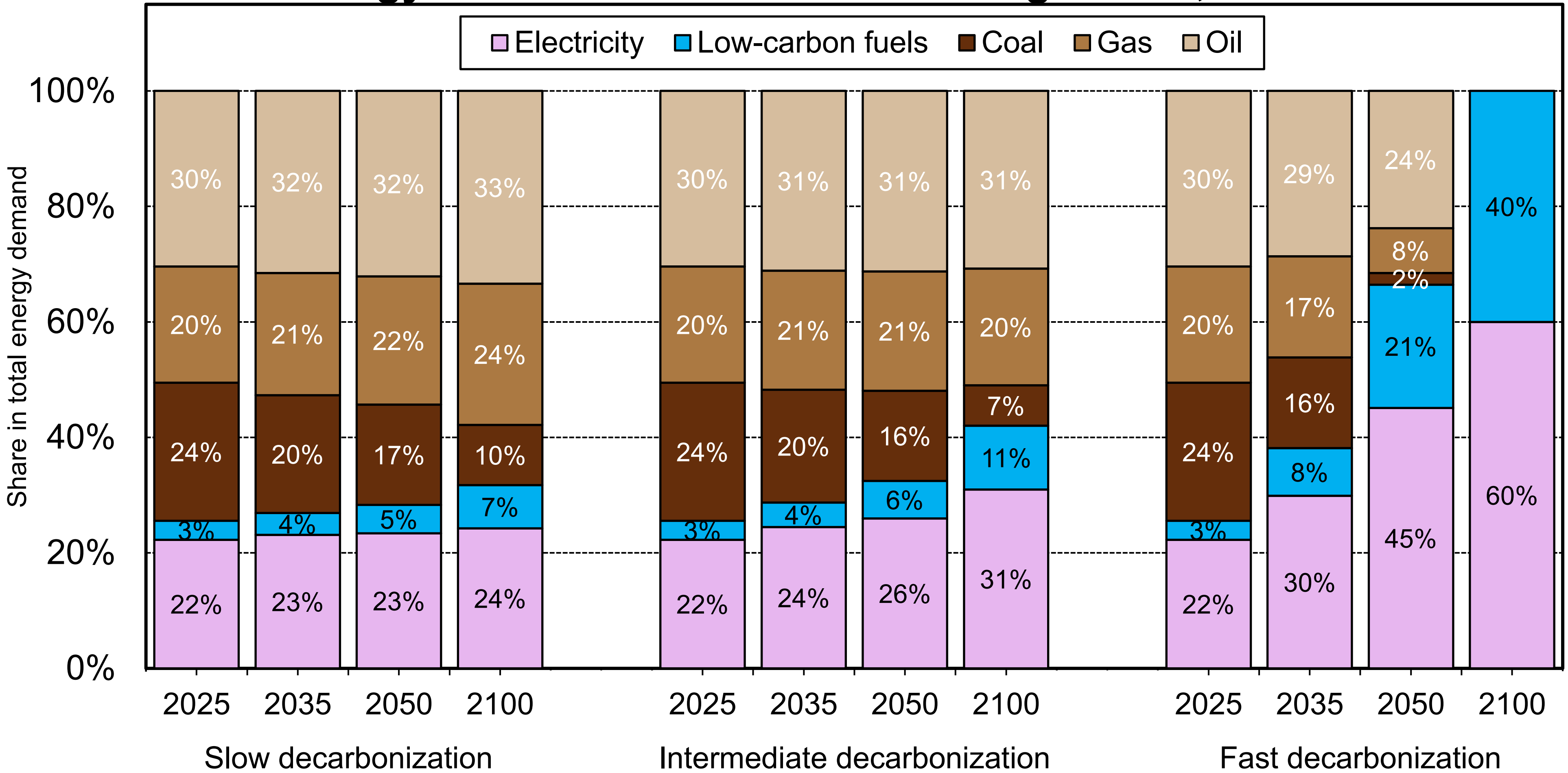
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives and pledges), with different speeds across production sectors. **Sources and series**: wseed.world (T3a)

Fig. 40b. Slow, Intermediate, and Fast Decarbonization: Energy Demand of the Construction Sector, 2025-2100



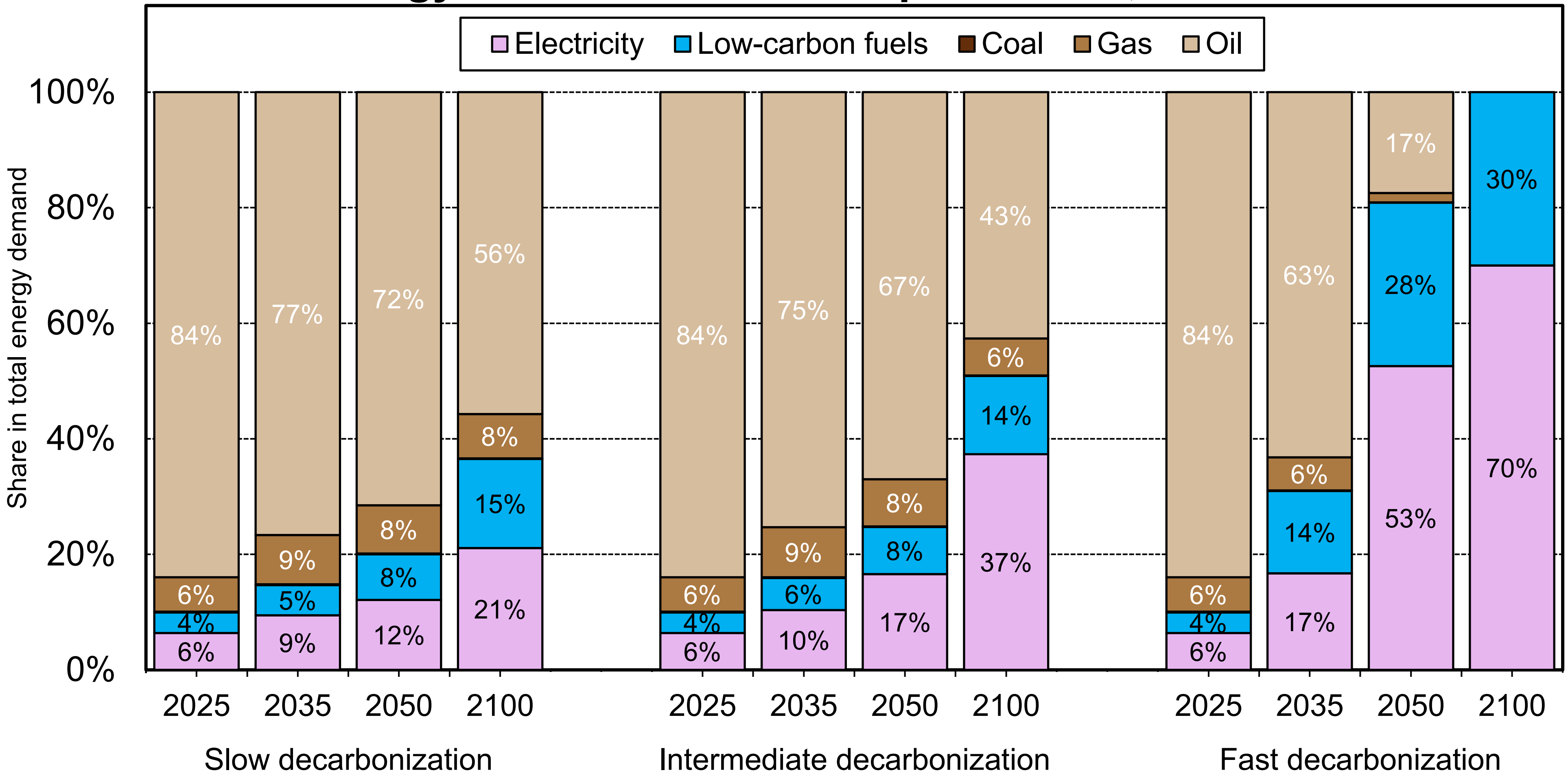
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives and pledges), with different speeds across production sectors. **Sources and series**: wseed.world (T3b)

Fig. 40c. Slow, Intermediate, and Fast Decarbonization: Energy Demand of the Manufacturing Sector, 2025-2100



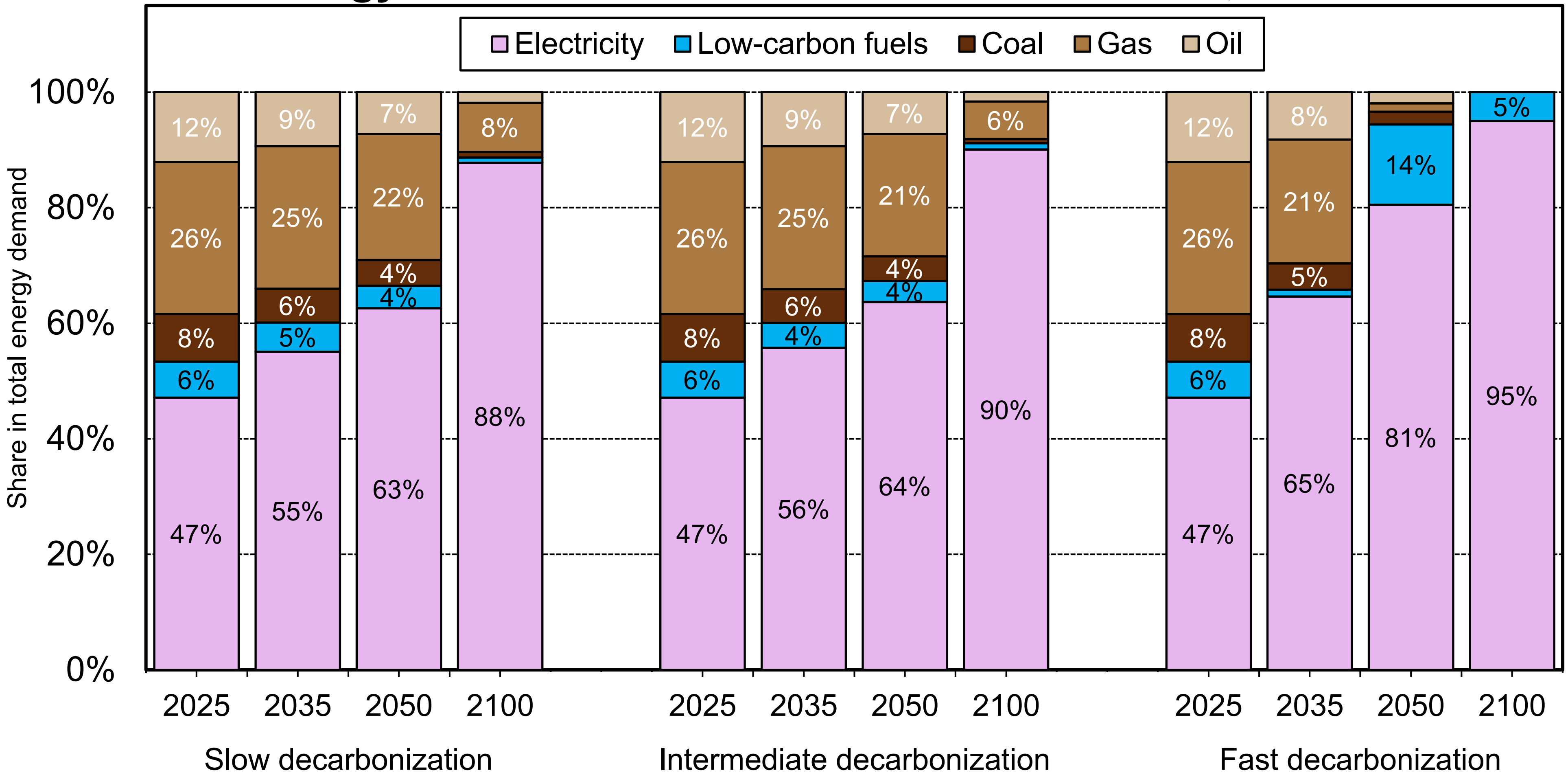
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives and pledges), with different speeds across production sectors. **Sources and series**: wseed.world (T3c)

Fig. 40d. Slow, Intermediate, and Fast Decarbonization: Energy Demand of the Transport Sector, 2025-2100



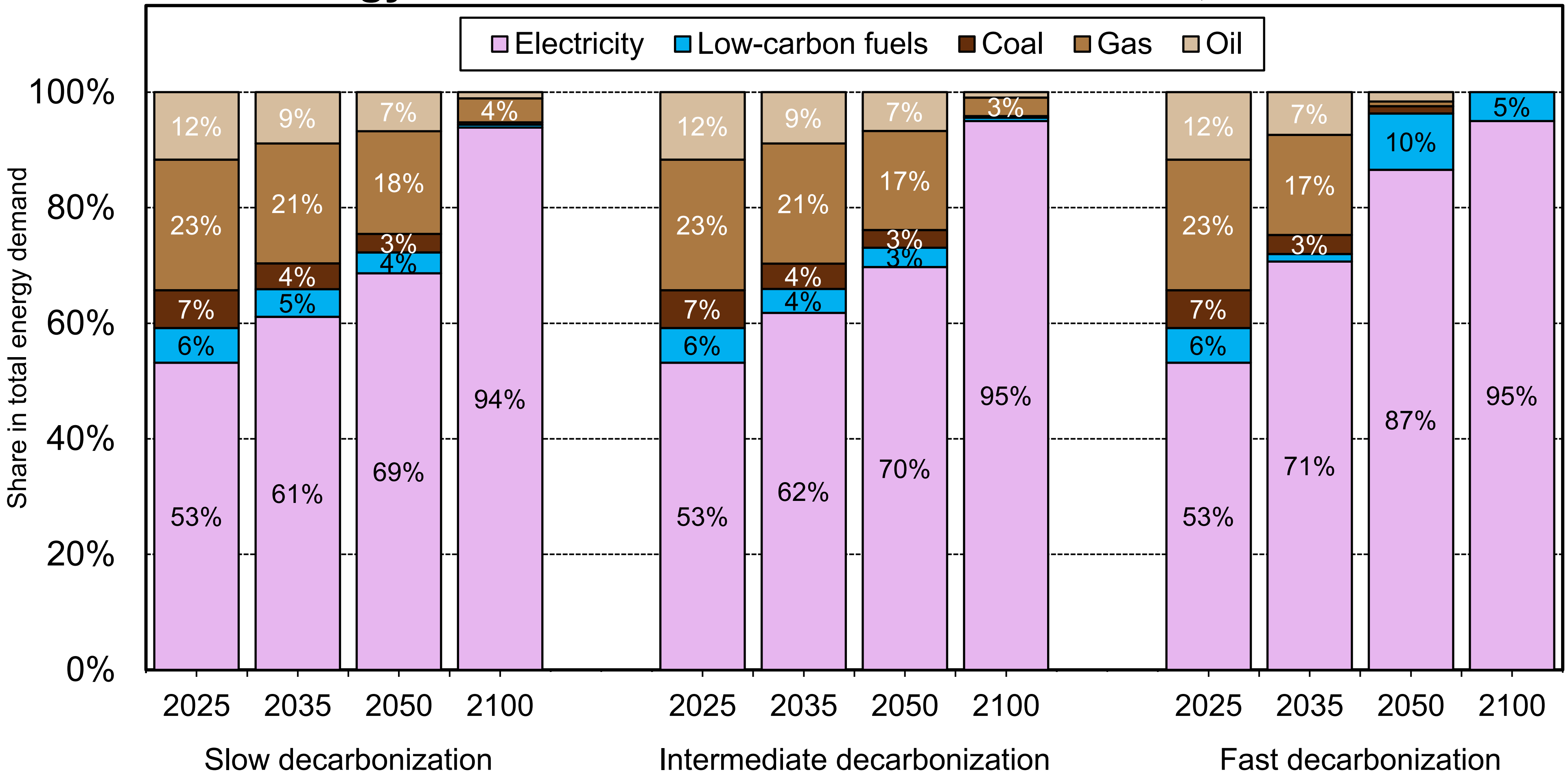
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives and pledges), with different speeds across production sectors. **Sources and series**: wseed.world (T3d)

Fig. 40e. Slow, Intermediate, and Fast Decarbonization: Energy Demand of the Education/Health Sector, 2025-2100



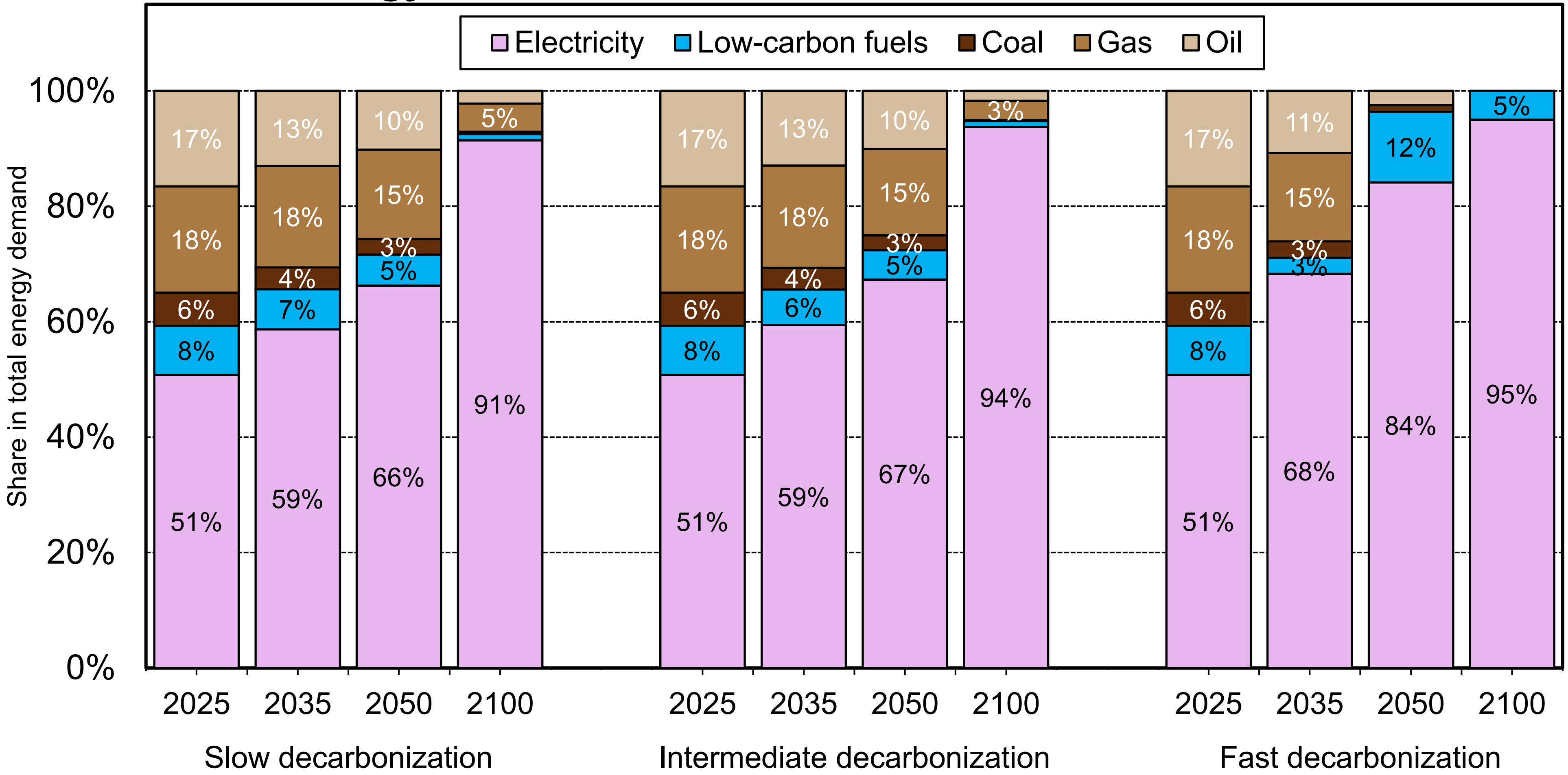
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives and pledges), with different speeds across production sectors. **Sources and series**: wseed.world (T3e)

Fig. 40f. Slow, Intermediate, and Fast Decarbonization: Energy Demand of the Leisure/Culture Sector, 2025-2100



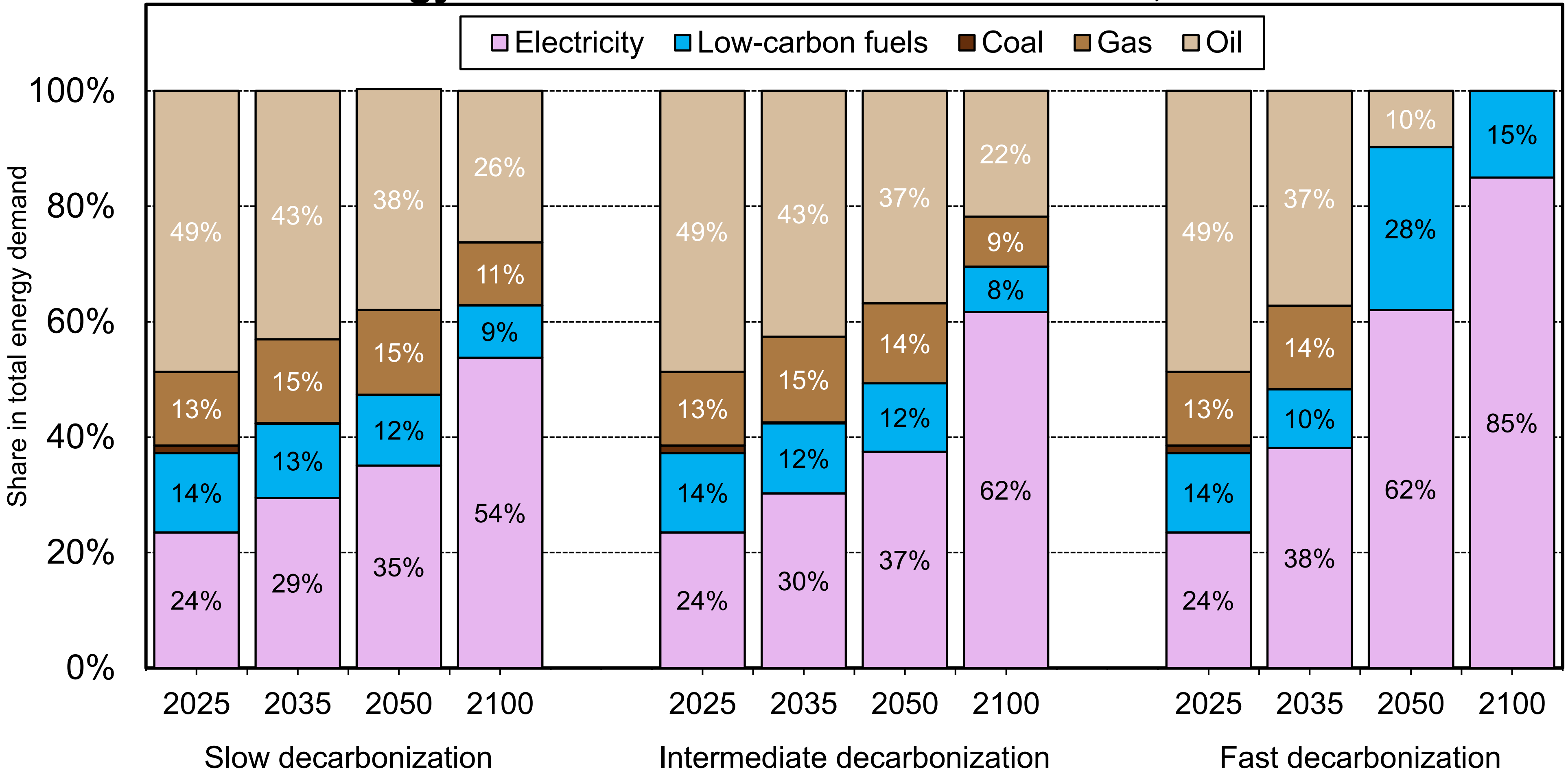
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives and pledges), with different speeds across production sectors. **Sources and series**: wseed.world (T3f)

Fig. 40g. Slow, Intermediate, and Fast Decarbonization: Energy Demand of the Other Services Sector, 2025-2100



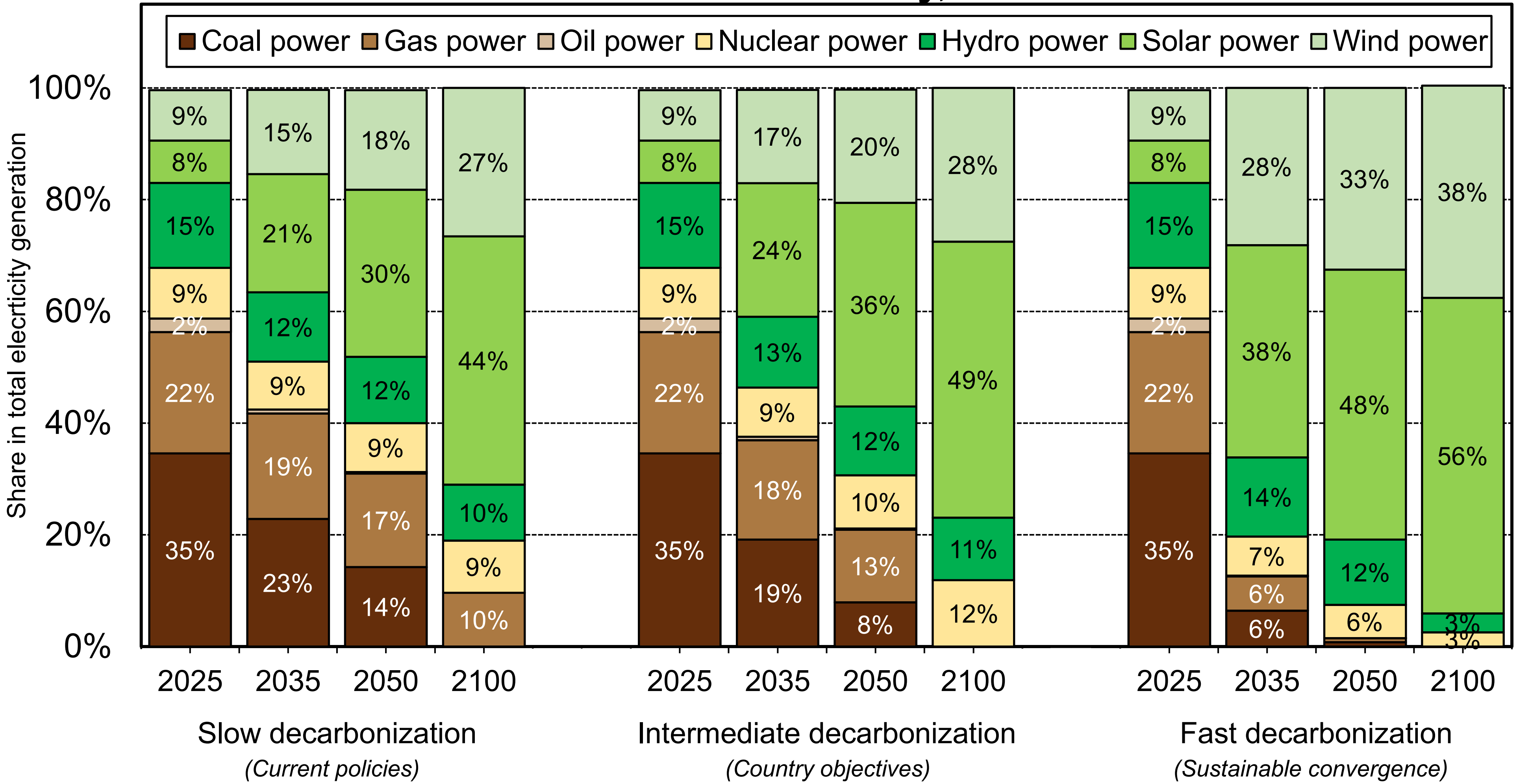
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives and pledges), with different speeds across production sectors. **Sources and series**: wseed.world (T3g)

Fig. 40h. Slow, Intermediate, and Fast Decarbonization: Energy Demand of the Household Sector, 2025-2100



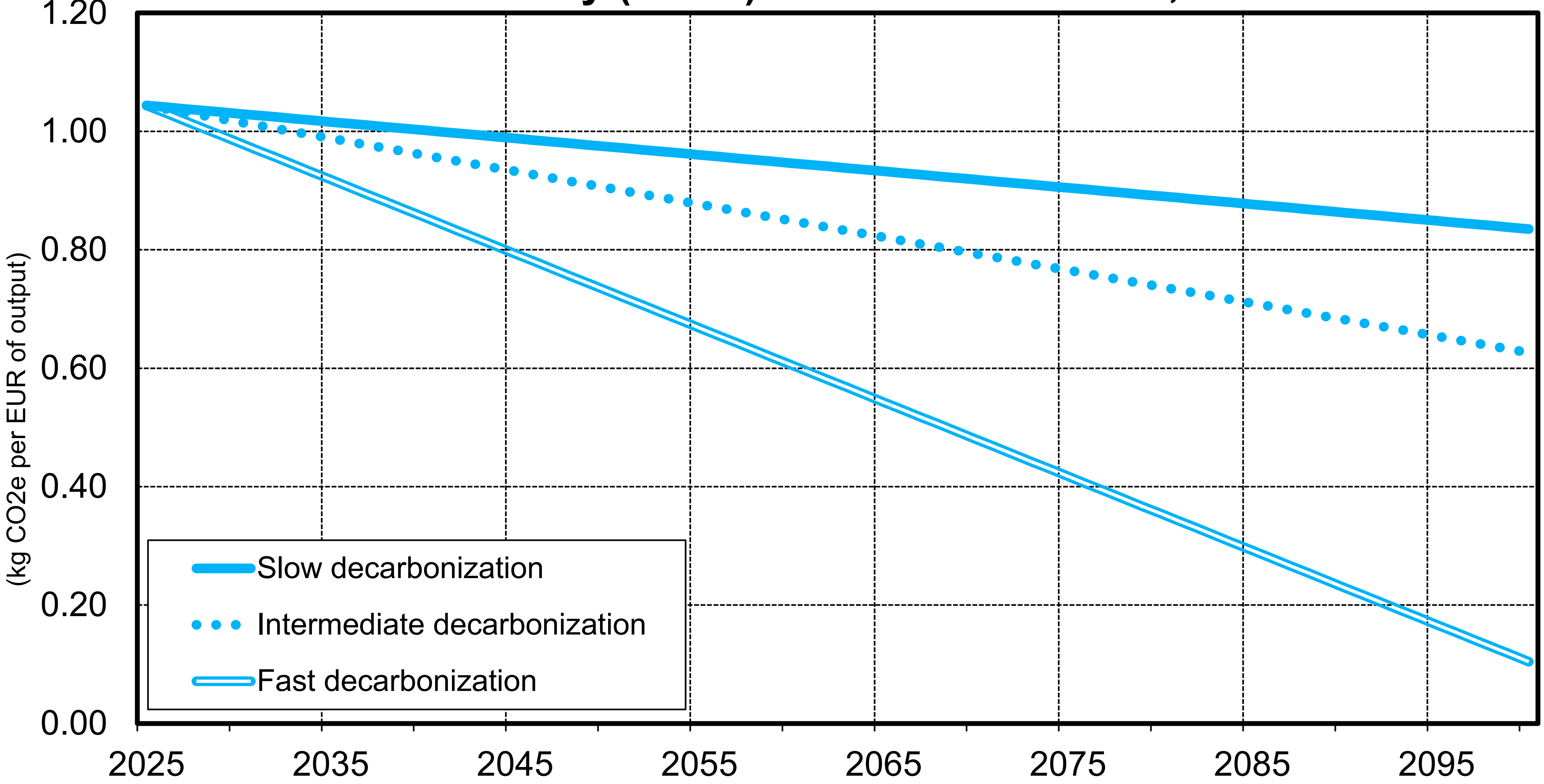
Interpretation. The Fast Decarbonization scenario (sustainable development) is characterized by large phase-out of fossil fuels as compared to both the Slow decarbonization scenario (current policies) and the Intermediate decarbonization scenario (official country objectives and pledges), with different speeds across production sectors. Note. The energy demand of the household sector corresponds to direct energy consumption by households, primarily for residential heating and personal vehicle use. **Sources and series**: wseed.world (T3h)

Fig. 41. Slow, Intermediate, and Fast Decarbonization: Generation of Electricity, 2025-2100



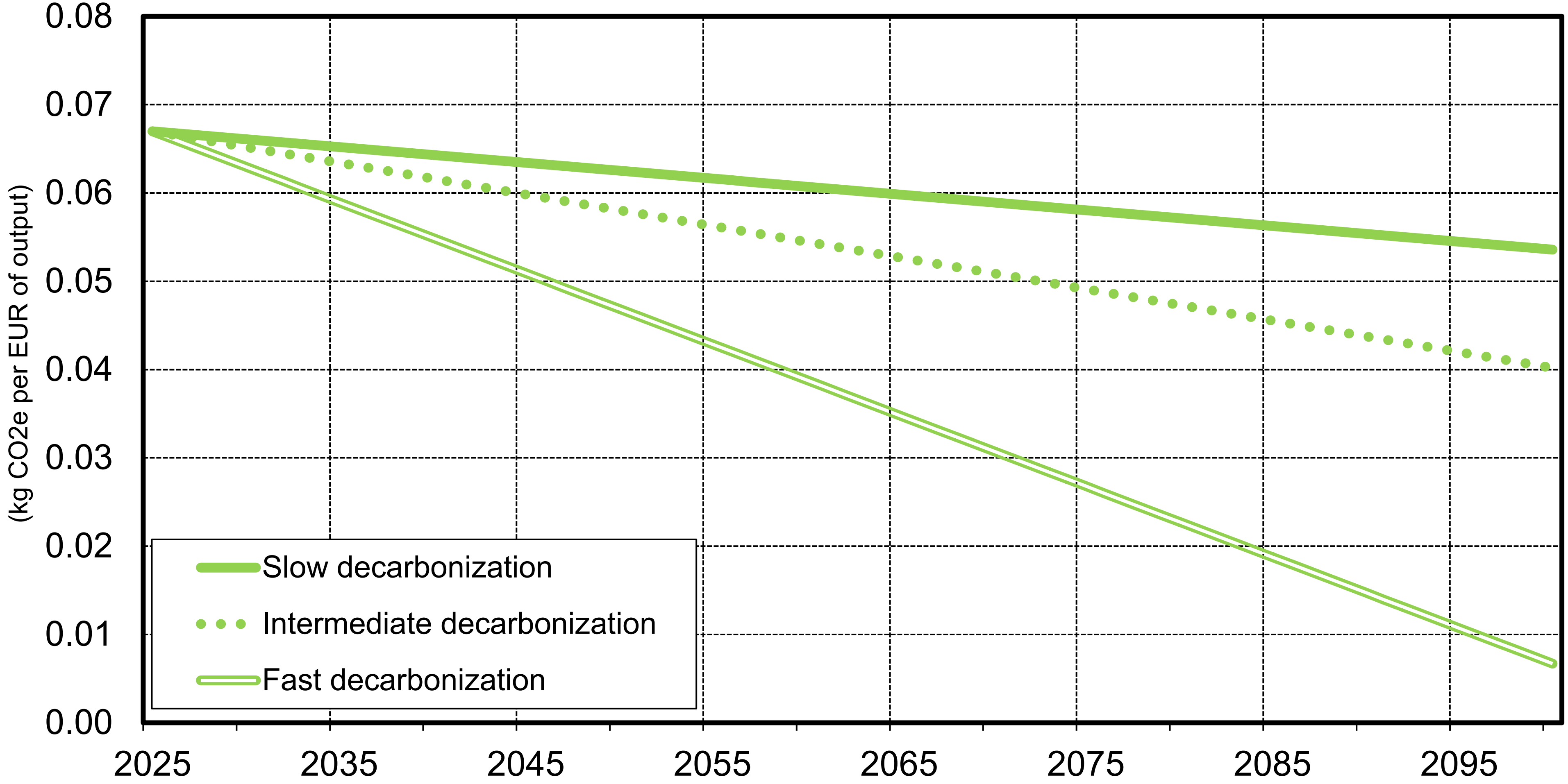
Interpretation. Under the sustainable convergence scenario (FD), the decarbonization of electricity should accelerate considerably as compared to both current policies (SD)) and official country objectives and pledges (ID). In particular, fossil fuel power should represent less than 1% of total electrity generation by 2050 (vs 31% and 21% according to SD and ID scenarios). **Sources and series**: wseed.world (T4)

Fig. 42a. Slow, Intermediate, and Fast Decarbonization: Emission Intensity (CO2e) of Water and Waste, 2025-2100



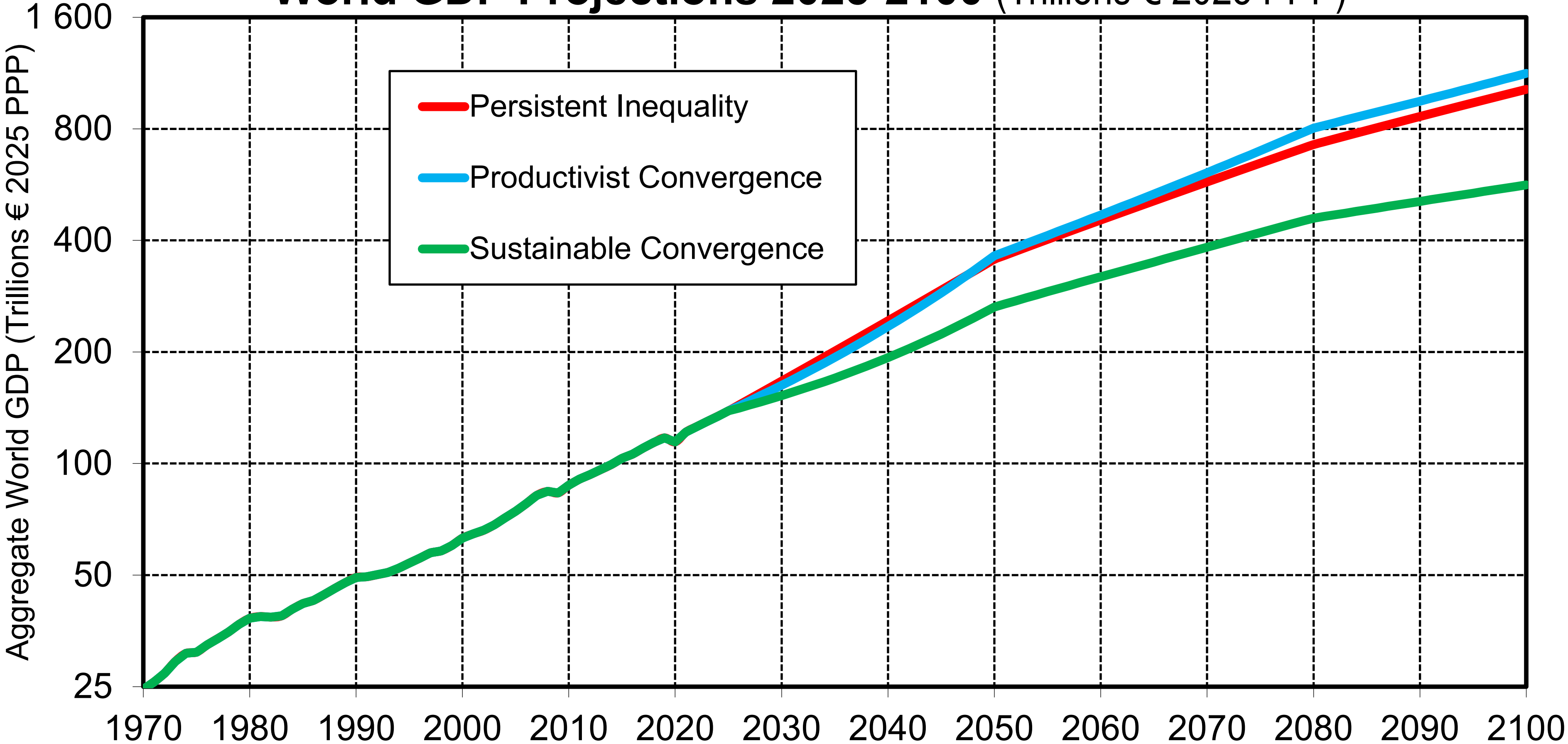
Interpretation. Under the sustainable convergence scenario (FD), the decline in GHG emissions intensities in industrial processes (water and waste, CO2 and other GGH) is projected to accelerate considerably as compared to both SD and ID scenarios.
Sources and series: wseed.world (T5a)

Fig. 42b. Slow, Intermediate, and Fast Decarbonization: Emission Intensity (CO2e) of Manufacturing, 2025-2100



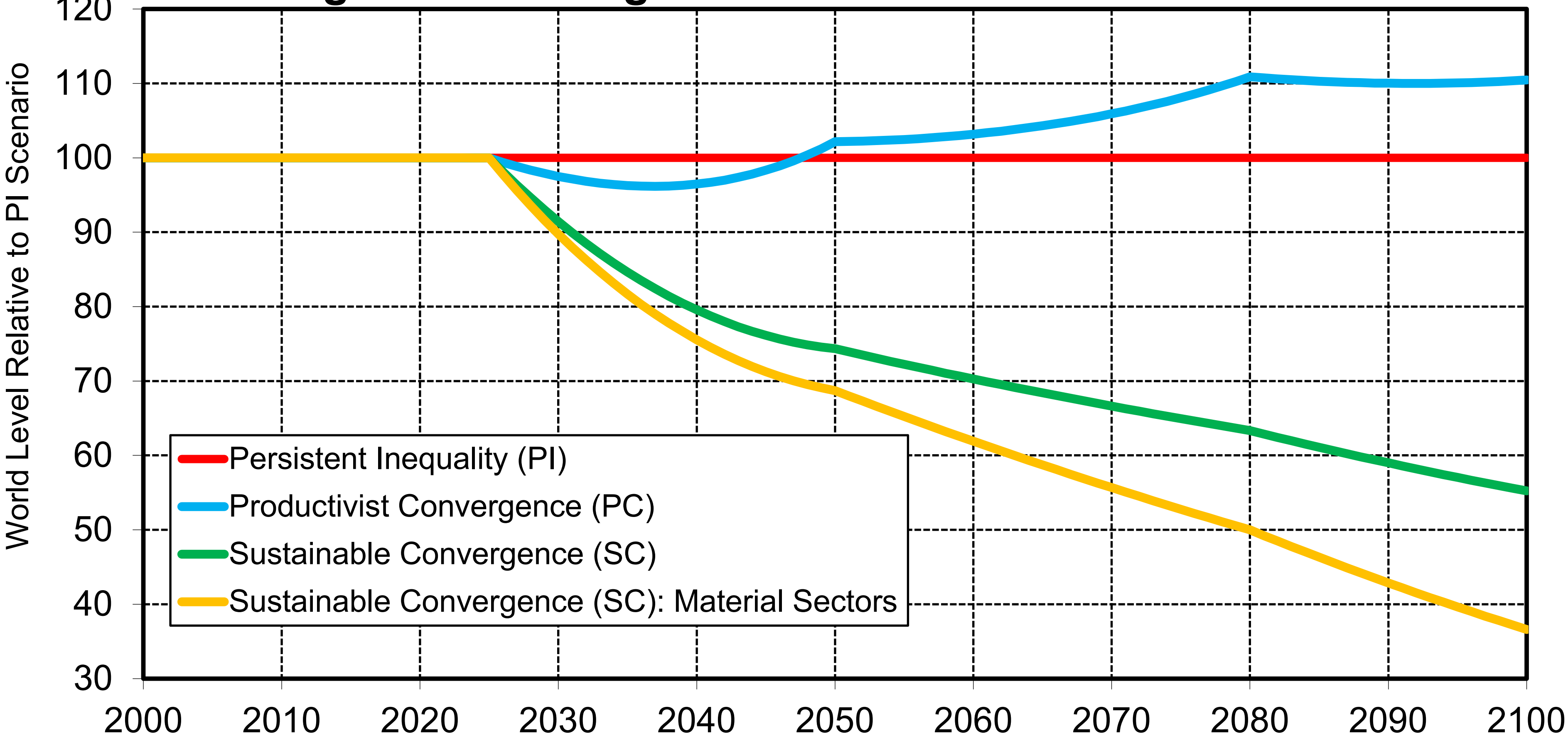
Interpretation. Under the sustainable convergence scenario (FD), the decline in GHG emissions intensities in industrial processes (manufacturing, CO2 and other GGH) is projected to accelerate considerably as compared to both SD and ID scenarios.
Sources and series: wseed.world (T5b)

Fig. 43a. Sustainable Convergence vs Other Scenarios: World GDP Projections 2025-2100 (Trillions € 2025 PPP)



Interpretation. According to the sustainable convergence scenario, aggregate world GDP rises from 139T (Trilllions Euros 2025 PPP) in 2025 to 565T in 2100, vs 1023T in the persistent inequality scenario and 1130T in the productivist convergence scenario. In effect, the real growth rate of world GDP, which was equal to 3.2% per year between 1970 and 2025, is projected to slow down to 1.9% per year between 2025 and 2100 in the sustainable convergence scenario, vs 2.7% and 2.8% per year in the other two scenarios. **Sources and series**: wseed.world (R0a)

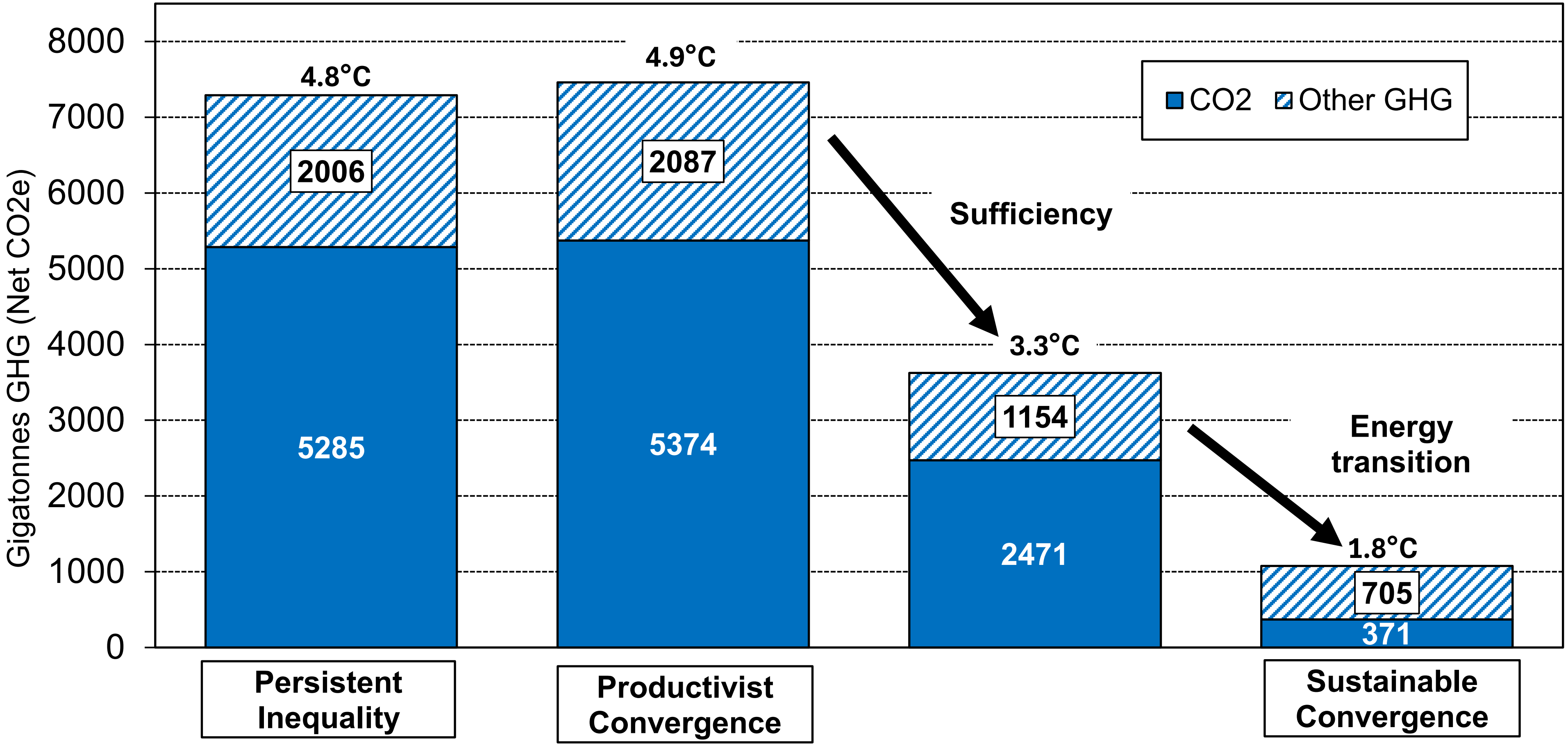
Fig. 43b. Sustainable Convergence Scenario: Large Material Degrowth Relative to Other Scenarios



Interpretation. According to the Sustainable Convergence scenario, aggregate world GDP is projected to be equal to 73% of the PI level (Persistent Inequality scenario) in 2050 and 55% in 2100. The fall is even larger if we focus on material sectors (food/agriculture, construction/housing, manufacturing, energy/mining, transport), where total world expenditure (final consumption and investment) in the SC scenario is projected to be equal to 67% of PI level in 2050 and 37% in 2100. **Sources and series**: wseed.world (R0b)

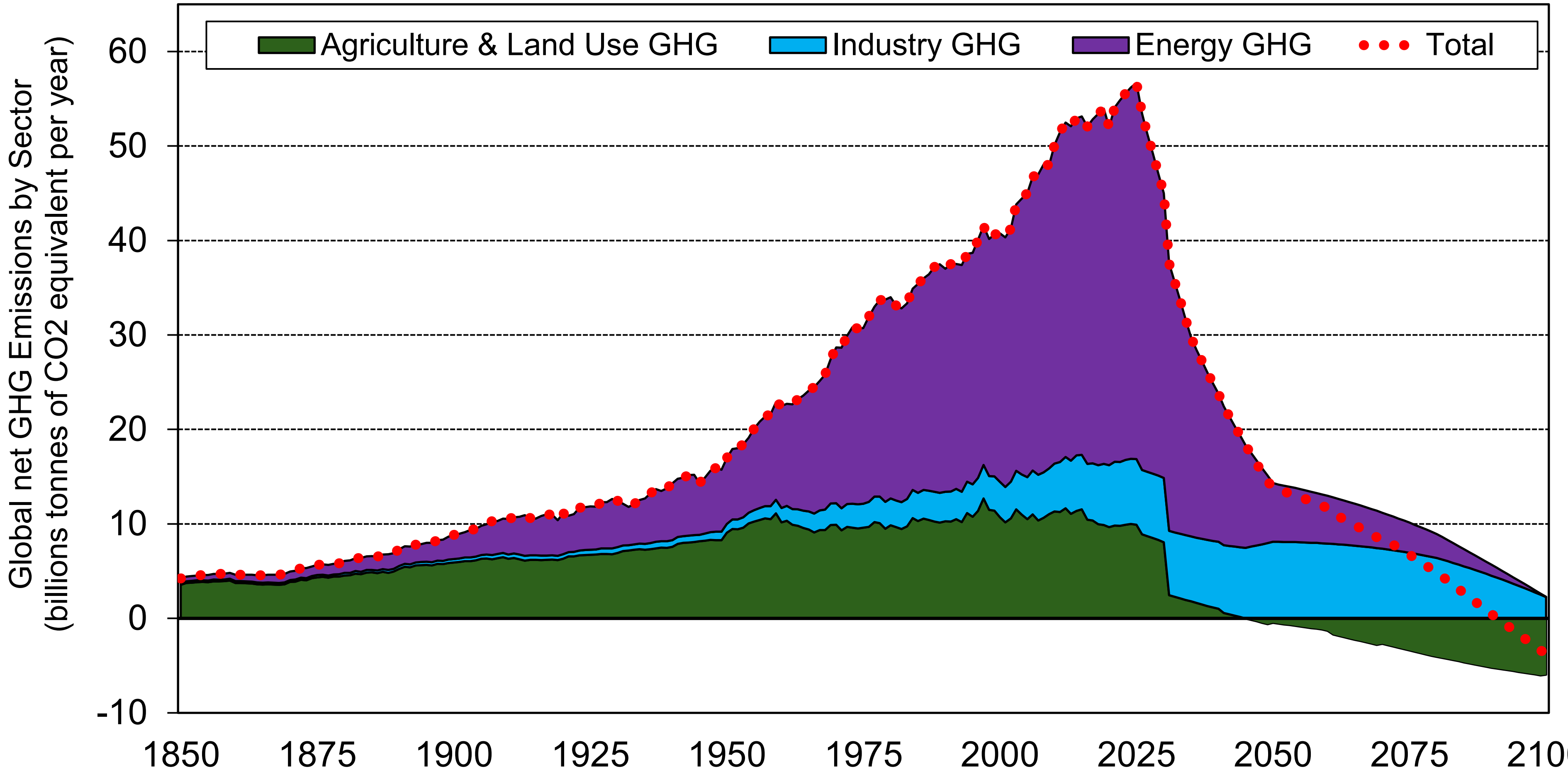
Fig. 44. Sufficiency & Energy Transition Are Complementary

(Projected Emissions & Temperature of Core Scenarios 2026-2100)



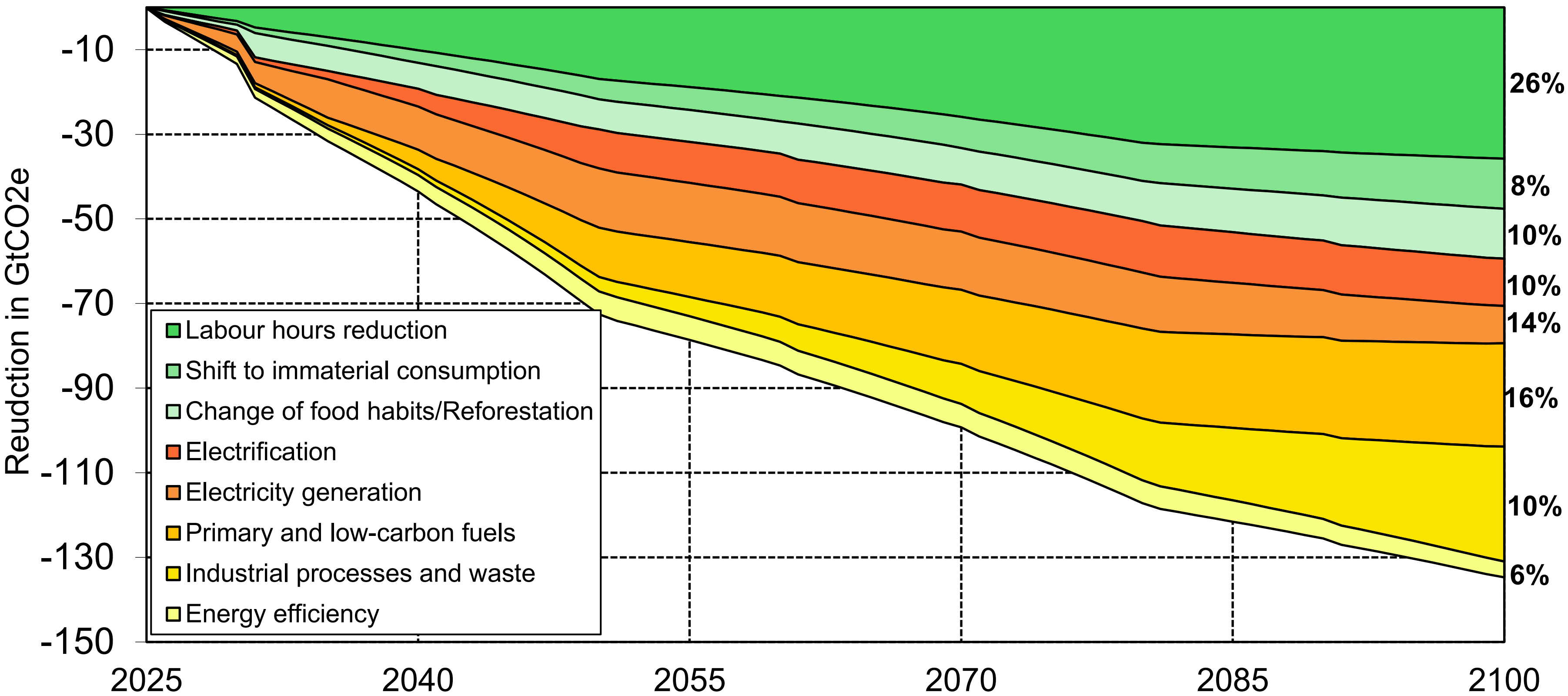
Interpretation. In order to reduce GHG emissions and keep warming below 2°, both socioeconomic sufficiency - including labour hours reduction, shift to immaterial consumption, change of food habits & implied reforestation - and energy system transformation play an indispensable and complementary role. **Notes.** The figure shows projected cumulative emissions and temperature rise of the core scenarios, where persistent inequality and productivist convergence come with slow decarbonization and sustainable convergence with fast decarbonization.. **Sources and series**: wseed.world (X1)

Fig. 45. Sustainable Convergence and Fast Decarbonization: The Key Role of Fossil Fuels Phase-Out & Deforestation Ban



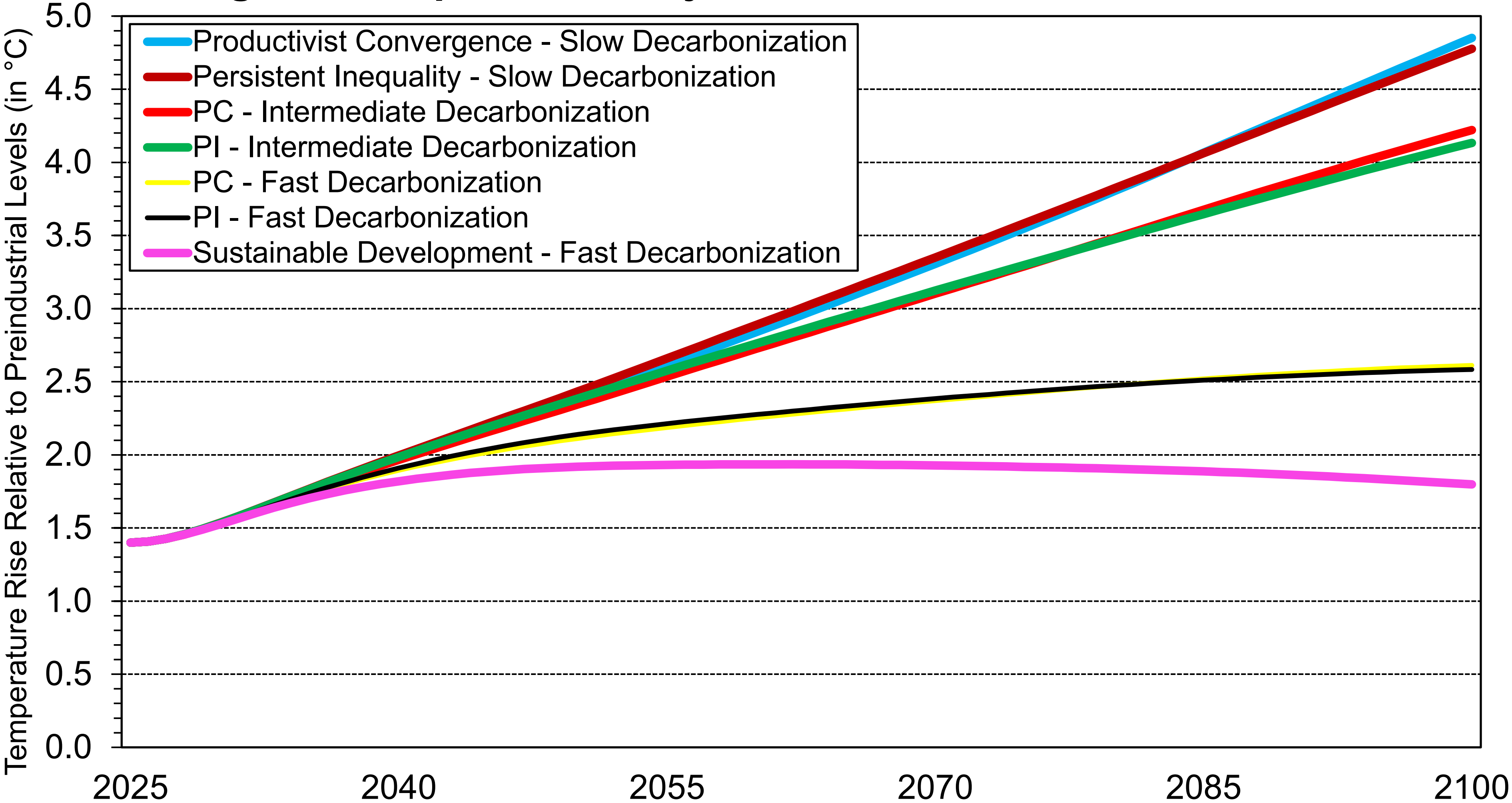
Interpretation. Under the sustainable convergence/fast decarbonization scenario, the sharp decline of GHG emissions over the 2026-2100 period is made possible by the rapid phase-out of fossil fuels (fall of Energy GHG) and a strict deforestation ban enforced in 2030, followed by gradual reforestation bringing world forest cover back to 1900 level by 2100 (leading to negative Agriculture & Land-Use GHG in 2050-2100, and slight negative total net GHG emissions by 2100). In contrast, Industry GHG (cement, waste, etc.) are more difficult to remove entirely.
Note: Observed series 1850-2025. Projected series 2026-2100 (Sustainable Convergence Scenario with Fast Decarbonization). **Sources and series**: wseed.world (X2)

Fig. 46. Sufficiency & Energy Transition Are Complementary
(Decomposition of Emissions Reduction Drivers 2026-2100)



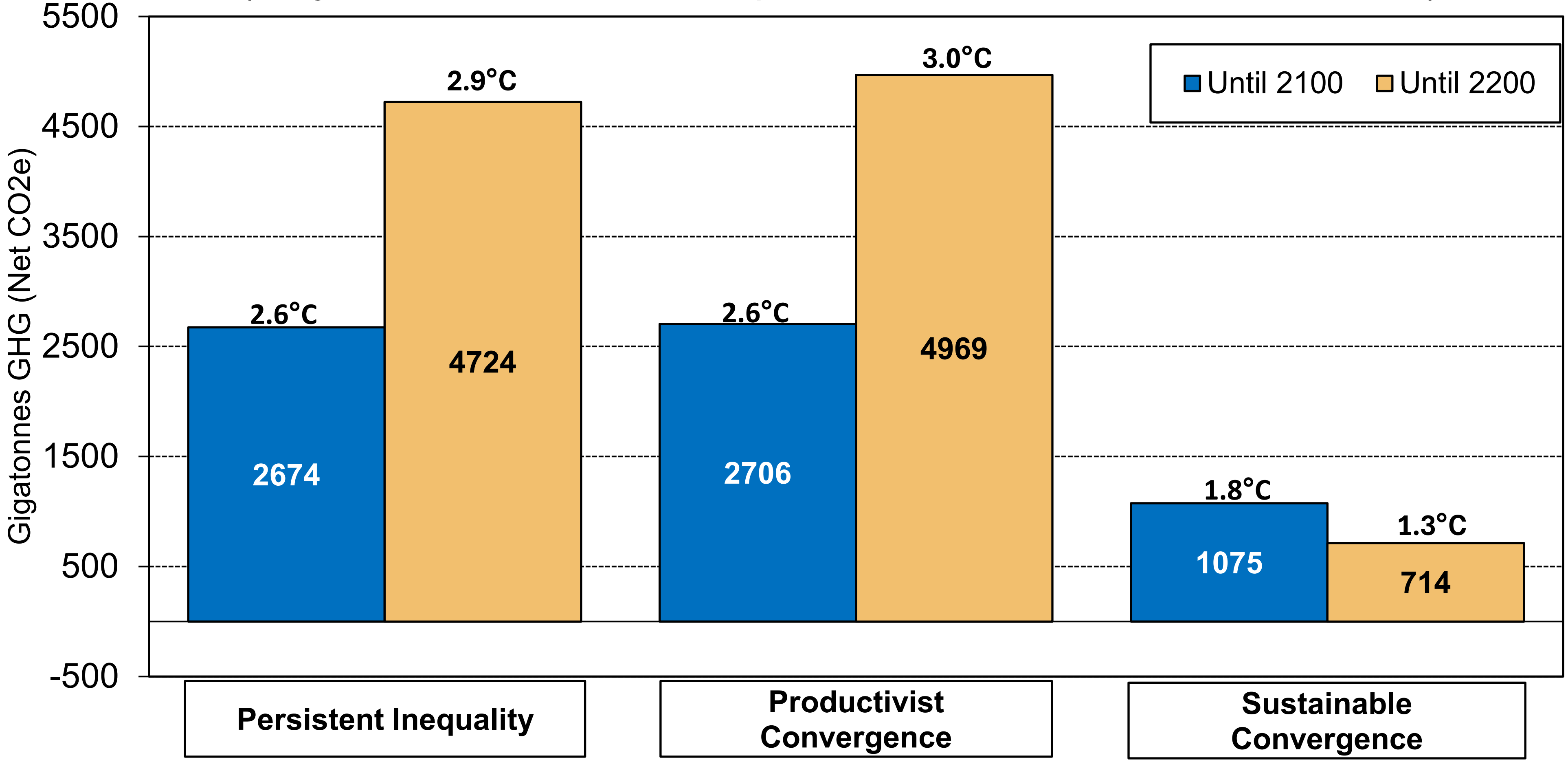
Interpretation. In order to reduce GHG emissions and keep warming below 2°, both socioeconomic sufficiency - including labour hours reduction, shift to immaterial consumption, change of food habits & implied reforestation - and energy system transformation play an indispensable and complementary role. **Notes:** The figure shows Shapley decomposition of the annual difference in emissions (in GTCO2e) between the Productivitst Convergence - Slow Decarbonization Scenario and the Sustainable Convergence - Fast Decarbonization Scenario. Percentage values on the right show contribution over entire 2025-2100 period. **Sources and series**: wseed.world (X3)

Fig. 47. Temperature Projections: Core Scenarios 2026-2100



Interpretation. The Sustainable Development/Fast Decarbonization scenario is the only one leading below 2°C by 2100. The PC and PI scenarios under Slow Decarbonization (current policies) lead to 4.8-4.9°C, while the PC and PI scenarios with Intermediate Decarbonization (official country commitments) lead to 4.1-4.2°C. The PC and PI scenarios with Fast Decarbonization lead to 2.6°C, but such a policy mix appears to be very unlikely. In any case, emissions and temperature rise would continue after 2100 under this scenario (no net zero emission).
Sources and series: wseed.world (X4)

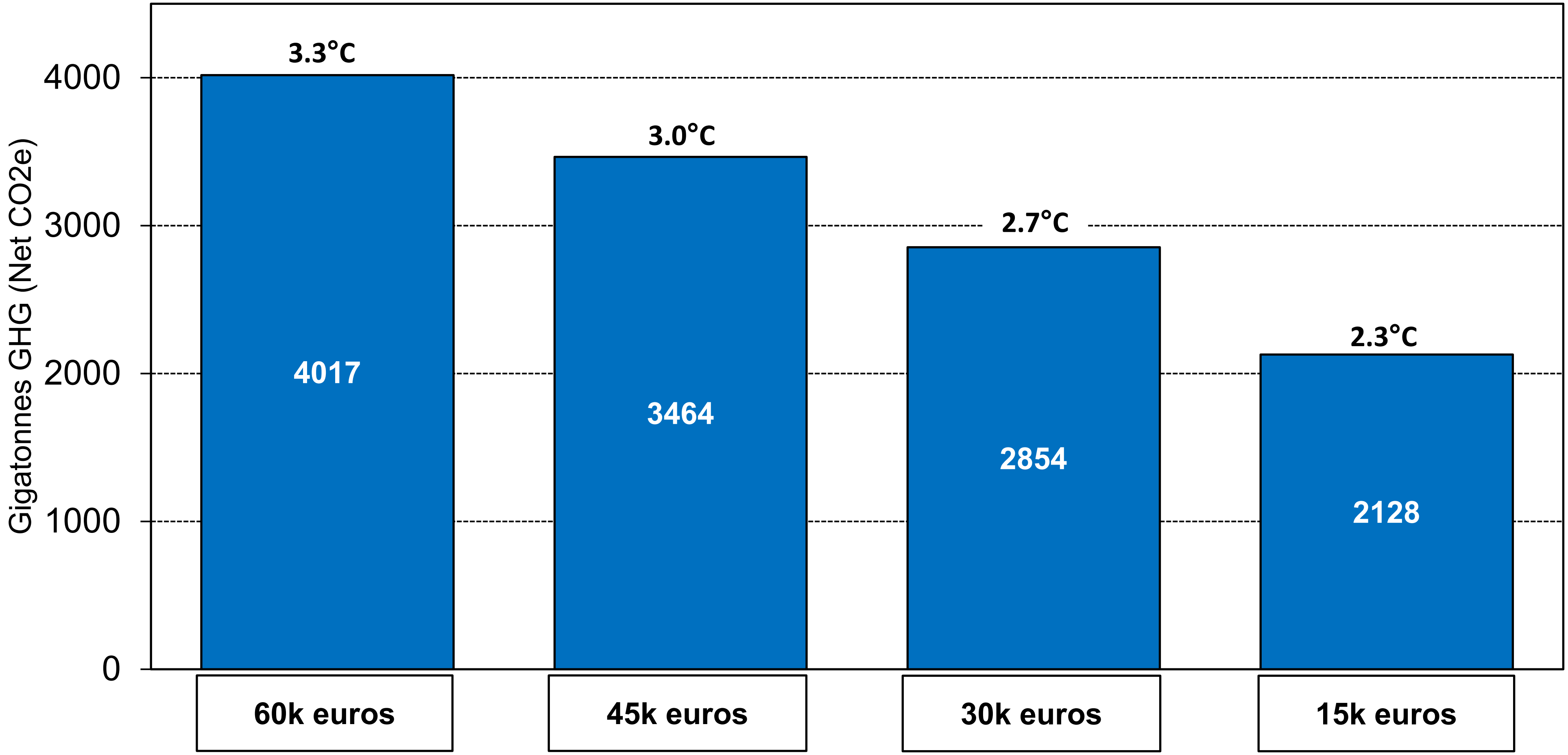
Fig. 48. Without Sufficiency, Emissions Will Continue After 2100
(Projected Emissions & Temperature under Fast Decarbonization)



Interpretation. In the unlikely situation where the PI and PC scenarios are combined with Fast Decarbonizaion, positive emissions and temperature rise will continue well beyond 2100. **Note.** The 2200 values are a simplistic approximation where we hold 2100 net emissions constant. They illustrate that Persistent Inequality and Productivist Convergence have not reached net zero by 2100. **Sources and series**: wseed.world (X5)

Fig. 49. Degrowth Without Structural Change is not Enough

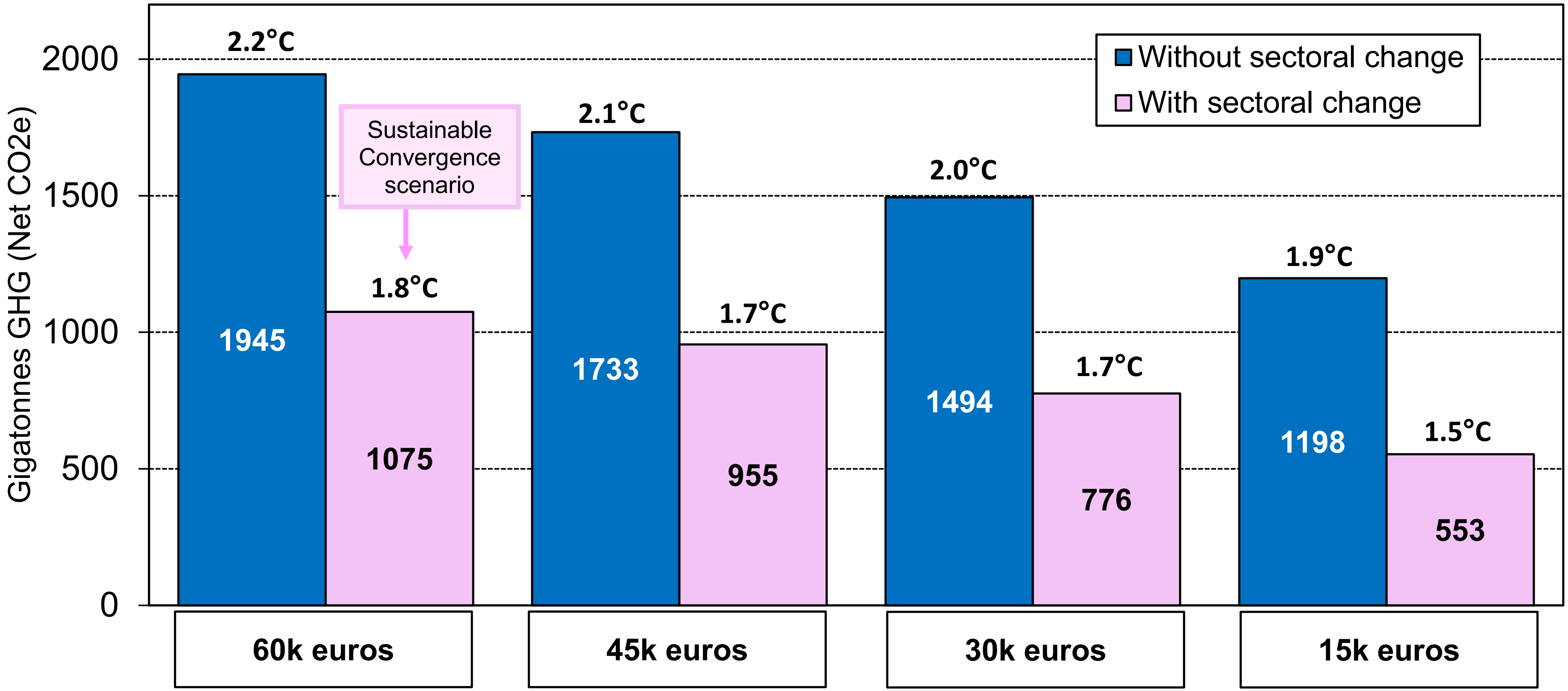
(Projected Emissions & Temperature With Intermediate Decarbonization)



Interpretation. In the absence of structural change (no shift to immaterial consumption, no change in food habits & no implied reforestation), and under the assumption of Intermediate Decarbonization, the reduction of the per capita GDP target in 2100 (via shorter labour hours) is not sufficient to bring global warming below 2°C, even with a 15k Euros 2025 PPP per capita GDP target.
Sources and series: wseed.world (X6)

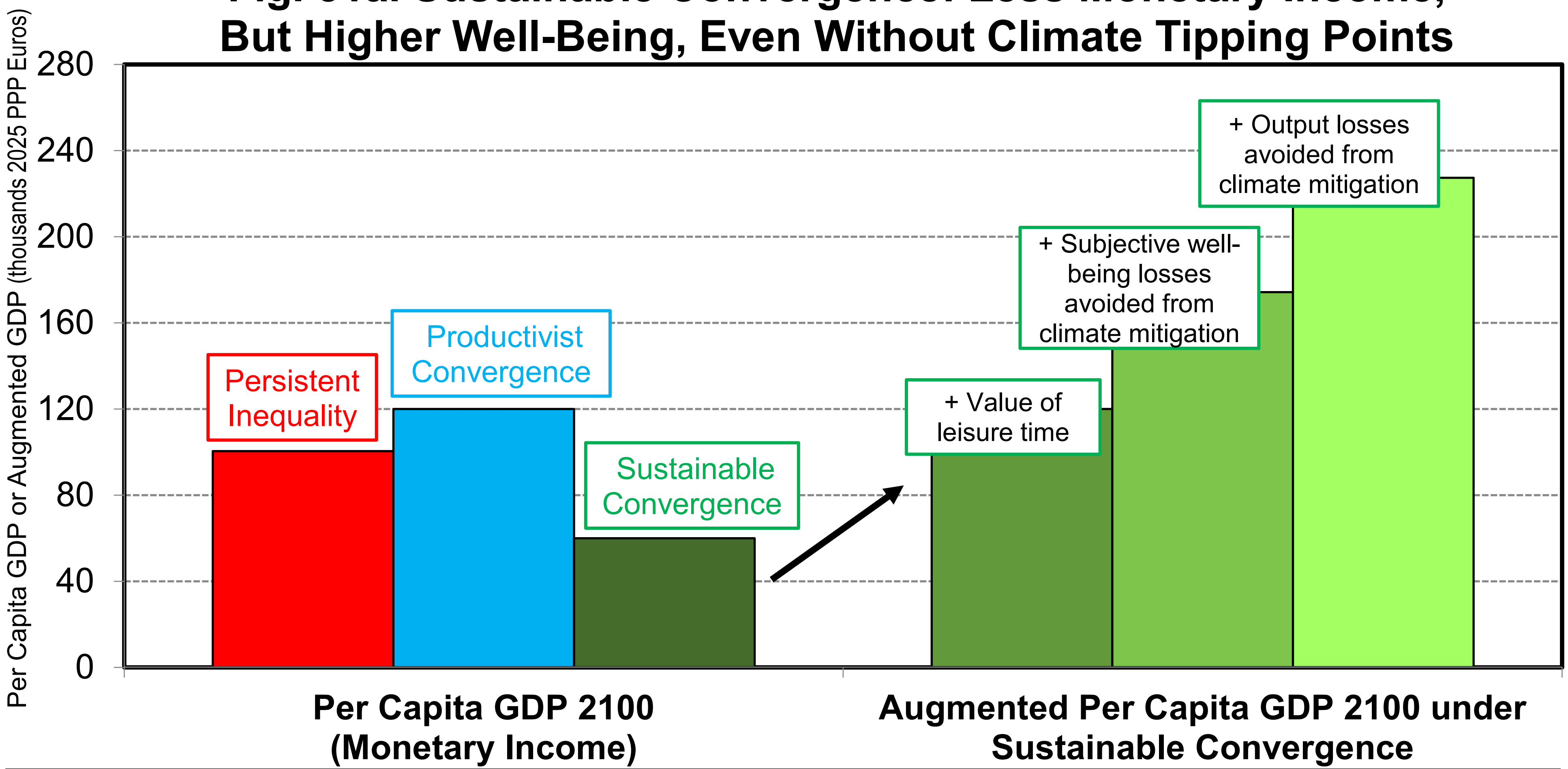
Fig. 50. Targeted Sufficiency Can Be More Effective Than Large Uniform Degrowth

(Projected Emissions & Temperature Under Fast Decarbonization)



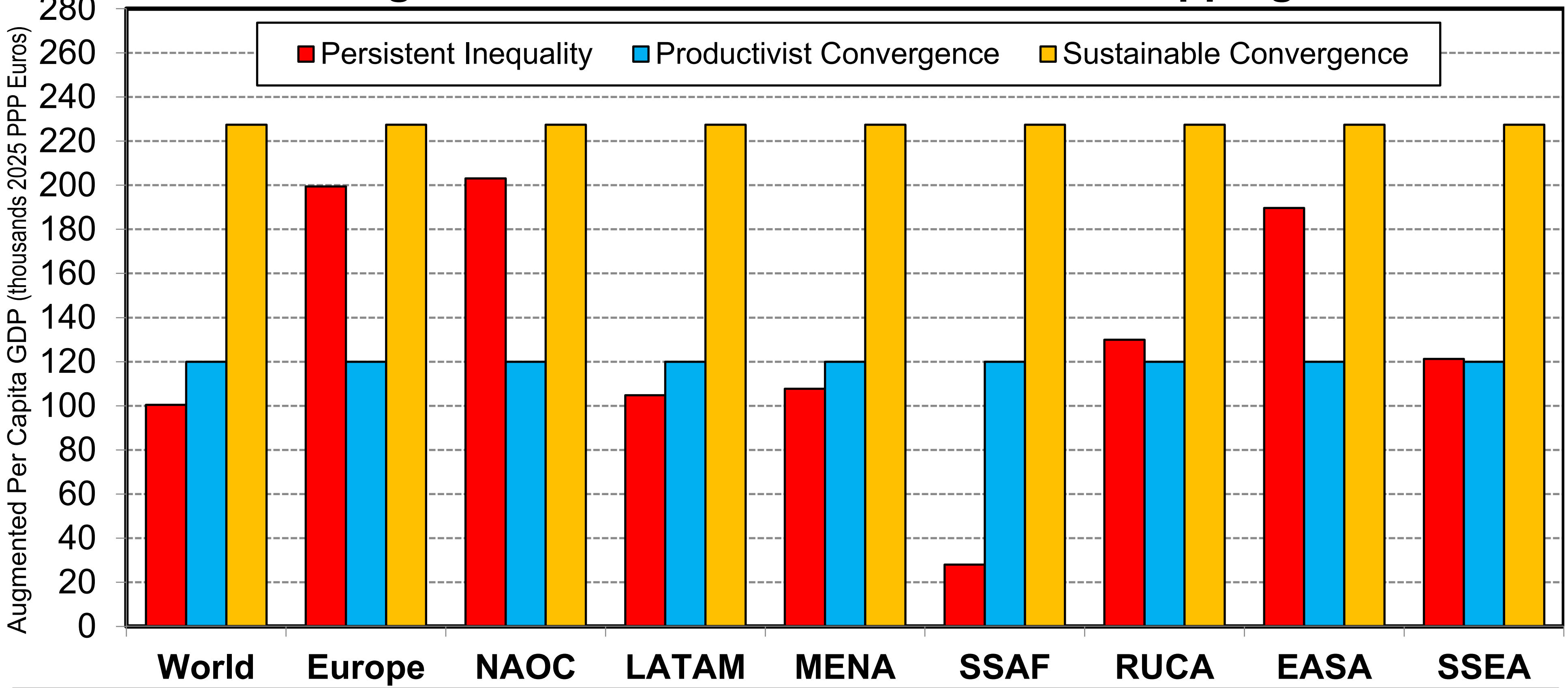
Interpretation. Targeted sufficiency, i.e. global convergence of all countries to 60k Euros 2025 PPP in per capita GDP by 2100, together with sectoral change (consumption shit to immaterial sectors, change in food habits & implied reforestation), leads to 1.8°C temperature rise in 2100, i.e. less than the 1.9°C associated to large uniform degrowth (15k for all in 2100) but no structural change. **Note**. It might be difficult to combine 15k with structural change, as this implies large reduction in average food intake. **Sources and series**: wseed.world (X7)

Fig. 51a. Sustainable Convergence: Less Monetary Income, But Higher Well-Being, Even Without Climate Tipping Points



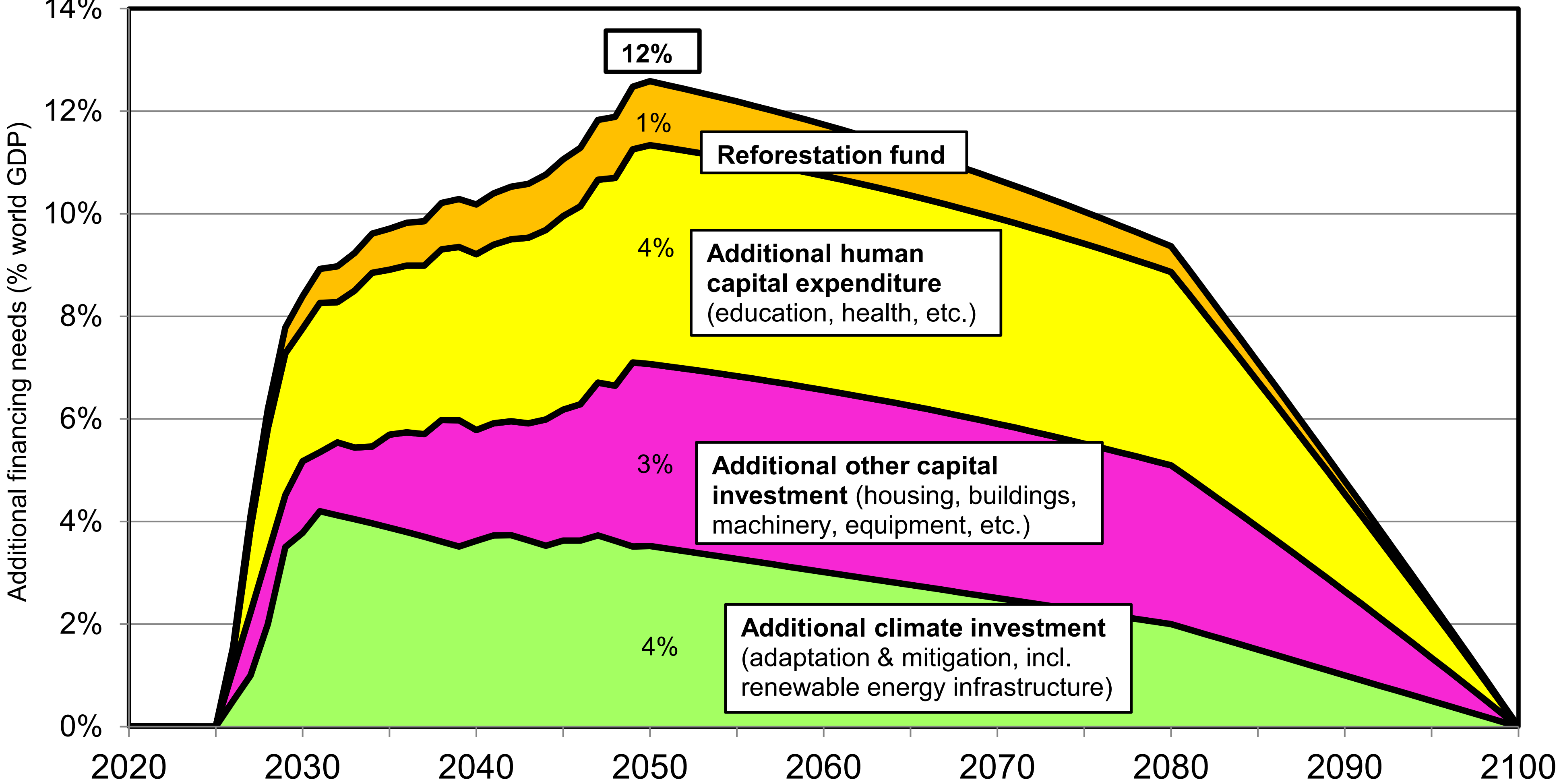
Interpretation. The Sustainable Convergence (SC) scenario leads to lower per capita GDP than other scenarios in 2100 but to higher well-being, once we include the value of extra free time (leisure) and a lower-bound estimate of the value of planetary habitability, as measured by the impact of lower temperatures on subjective well-being and output. This ignores potential catastrophic climate events and tipping points, which are nearly impossible to value in monetary terms. **Sources and series**: wseed.world (R1a)

Fig. 51b. Sustainable Convergence: Higher Well-Being in All Regions in 2100, Even Without Climate Tipping Points



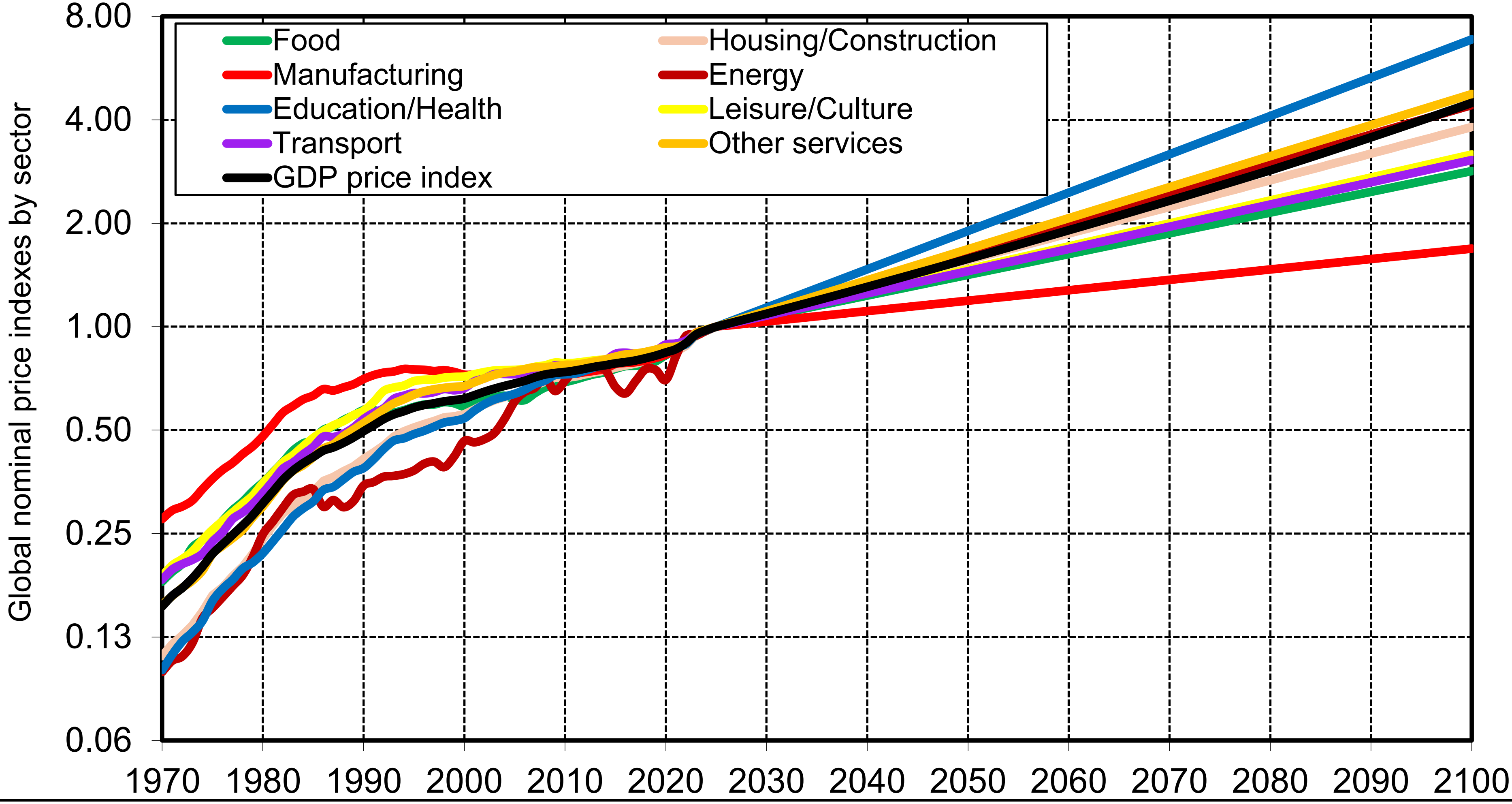
Interpretation. The Sustainable Convergence (SC) scenario leads to higher augmented per capita GDP (comprehensive well-being indicator, including value of extra free time and planetary habitability) than other scenarios in all world regions in 2100. However the gap is relatively small for the world's richest regions, & can even turn negative for some countries during the transition period 2025-2100. This ignores potential catastrophic climate events and tipping points, which are nearly impossible to value in monetary terms. **Note.** NAOC: North America/Oceania. LATAM: Latin America. SSAF: Subsaharan Africa. RUCA: Russia/Central Asia. EASA: East Asia. SSEA: South & Southeast Asia. **Sources and series**: wseed.world (R1b)

Fig. 52. Sustainable Convergence Scenario: Total Additional Financing Needs 2025-2100 (% world GDP)

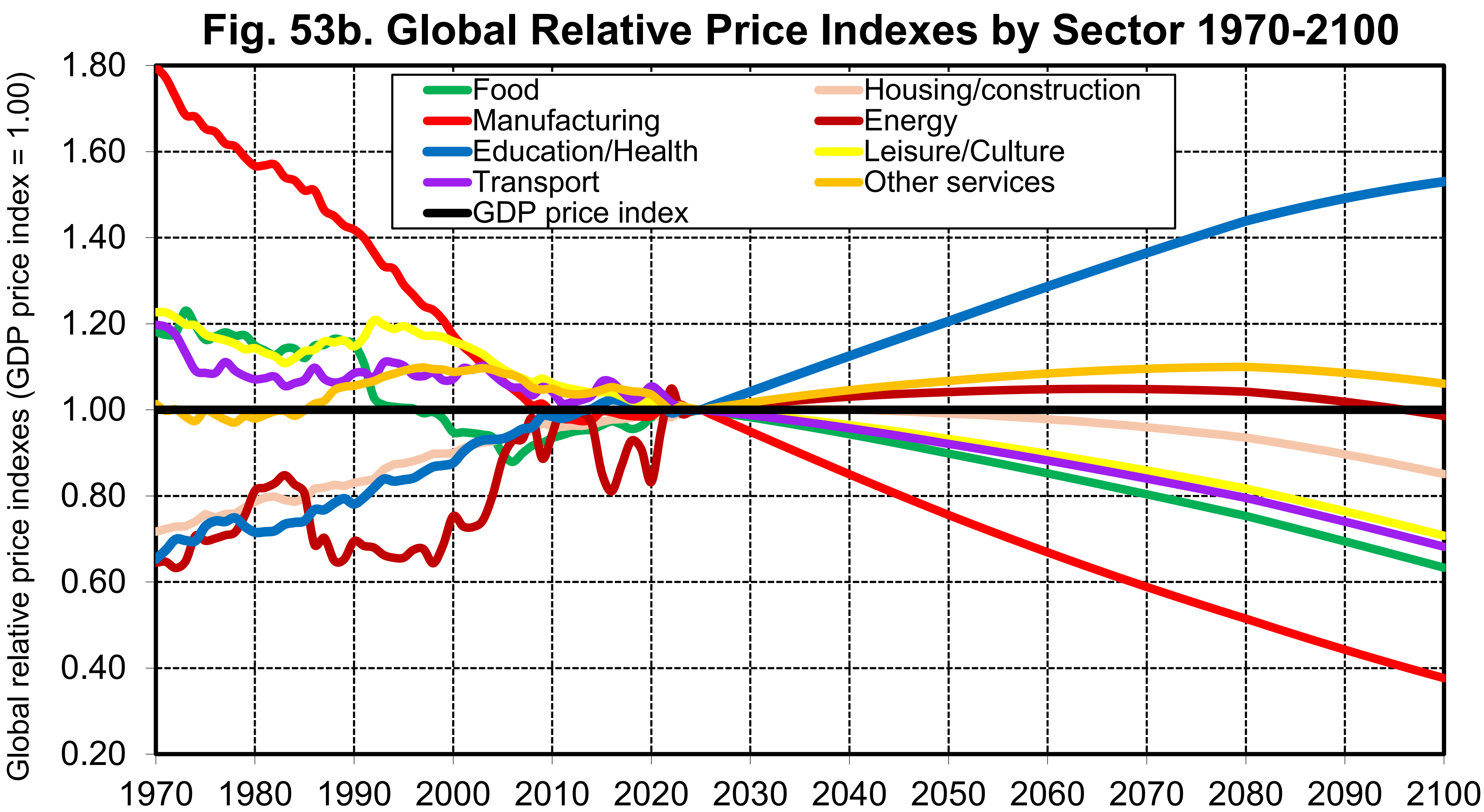


Interpretation. According to our projections, the Sustainable Convergence scenario requires total additional financing for capital investment, human capital expenditure and reforestation fund around 12% of world GDP by 2050 (as compared to Persistent Inequality or Productivist Convergence). Additional financing needs around 2030-2060 are projected to vary from about 3-4% of GDP in Europe/North America up to about 15-20% of GDP in Subsaharan Africa/South & Southeast Asia. **Sources and series**: wseed.world (Jx0)

Fig. 53a. Global Nominal Price Indexes by Sector 1970-2100



Interpretation. GDP price inflation has been 3.6% per year on average at the world level between 1970 and 2025 and is projected to be 2.0% over the 2025-2100 period. Inflation has always been lower in material sectors than in immaterial sectors (e.g. in manufacturig sector vs education/health), due to differential rates of technical change and is projected to follow the same pattern in 2025-2100. **Sources and series**: wiseed.world (C0a)



Interpretation. Price inflation has generally been smaller in material sectors than in immaterial sectors, due to differential rate of technical change, and is projected to follow the same pattern in 2025-2100. In effect, the relative price of manufacturing goods has been almost divided by 2 over 1970-2025 and is projected to be divided by more than 2 over 2025-2100. This corresponds in both cases to a relative price effect of about 0.5-1.0% per year relative to general GDP price index. **Sources and series**: wseed.world (C0b)